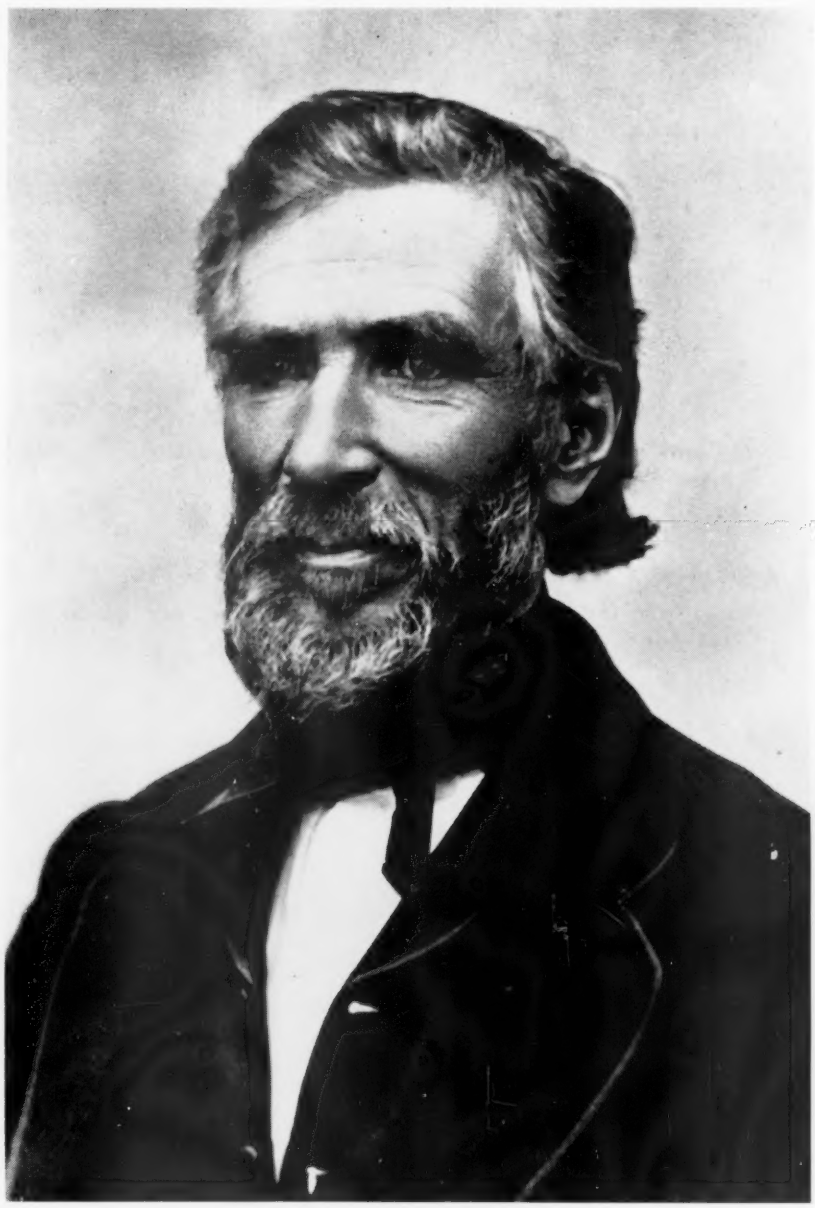
Vol. 20, No. 10 (October), pp. 337–374 (1941)

# THE BULLETIN

OF THE

# AMERICAN CERAMIC SOCIETY

Volume 20 NOVEMBER, 1941 Number 11



JAMES ROBERTSON

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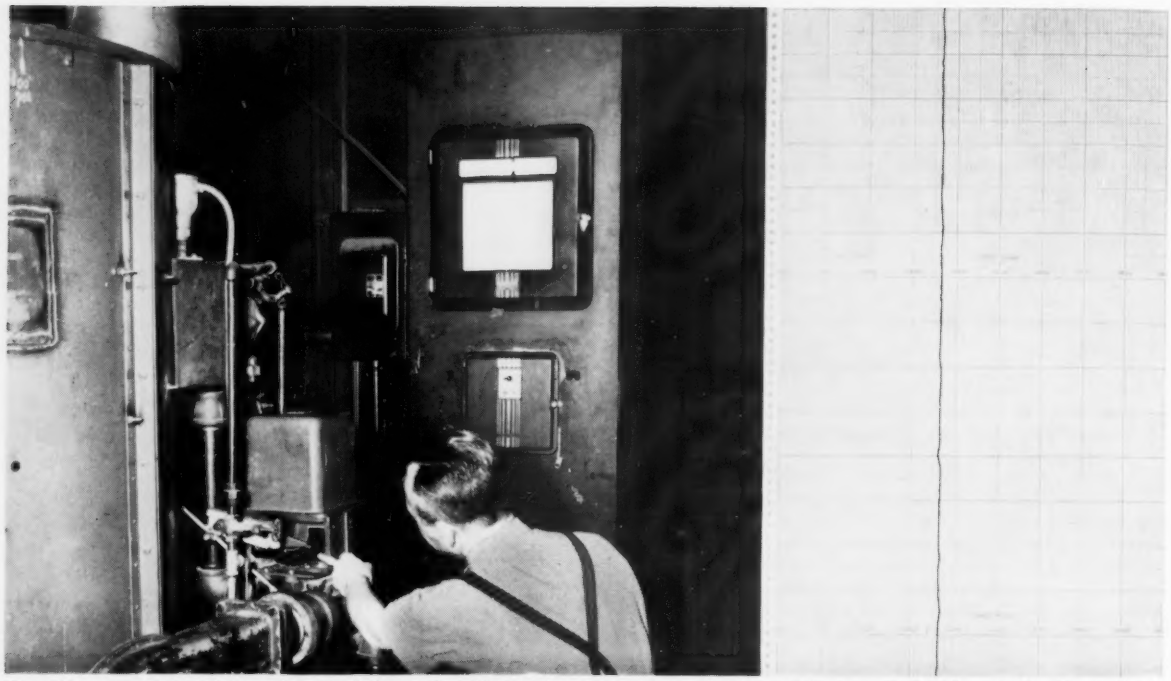
THE BULLETIN OF THE AMERICAN CERAMIC SOCIETY



The Micromax Controller on the panel shows that it's holding temperature steady, and the man is looking at the Controller's valve-drive to see the motion by which the instrument causes such control.

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*Publication Office:* 20th & Northampton Sts., Easton, Pa.
*Editorial, Executive, and Advertising Offices:* 2525 N. High St., Columbus, Ohio.
*Committee on Publications:* J. D. SULLIVAN, *Chairman;* D. E. SHARP, E. E. MARBAKER, J. B. AUSTIN, ROSS C. PURDY.

**Entered as second-class matter at the post office at Easton, Pa., under the act of March 3, 1879. Published monthly.**
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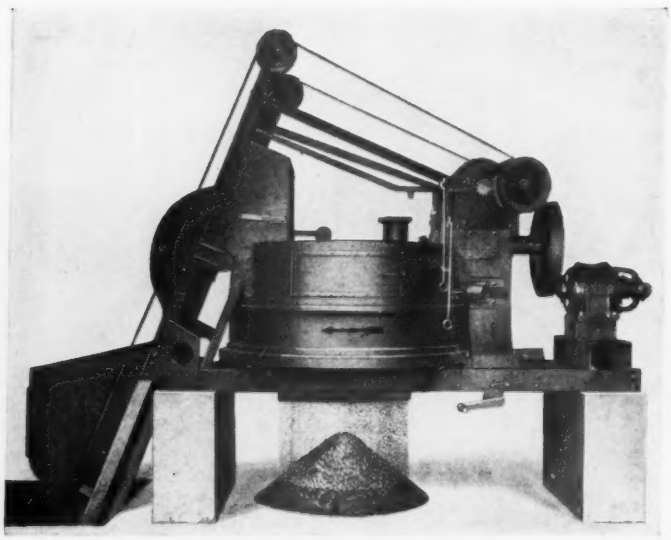

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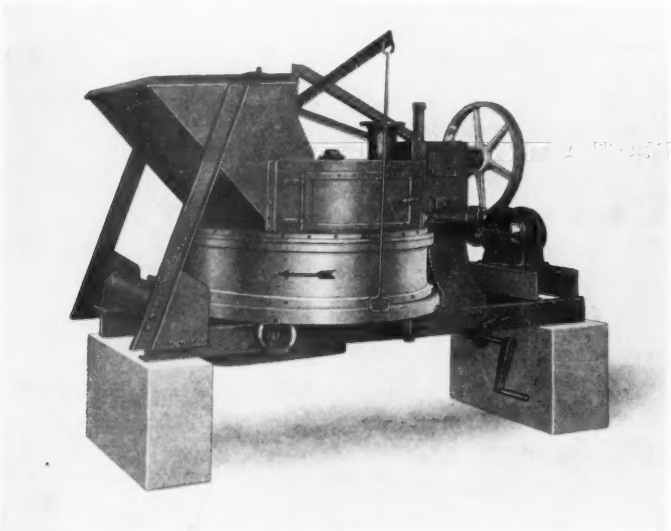

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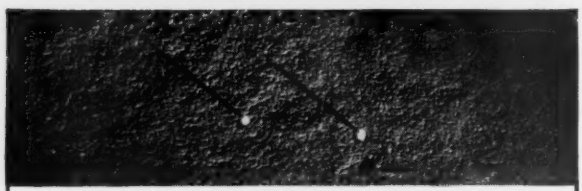

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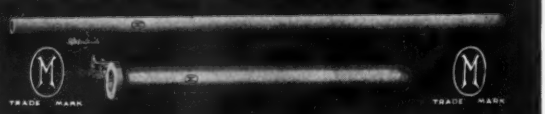

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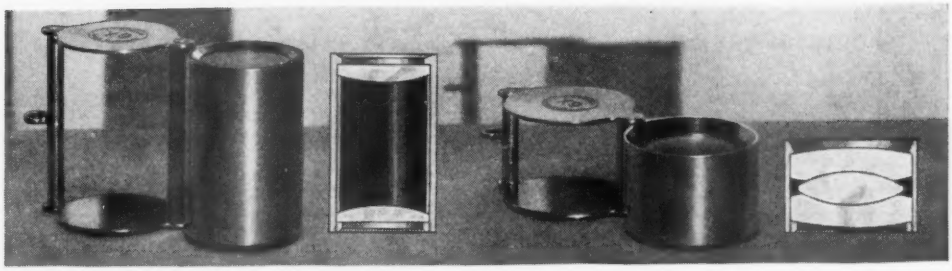

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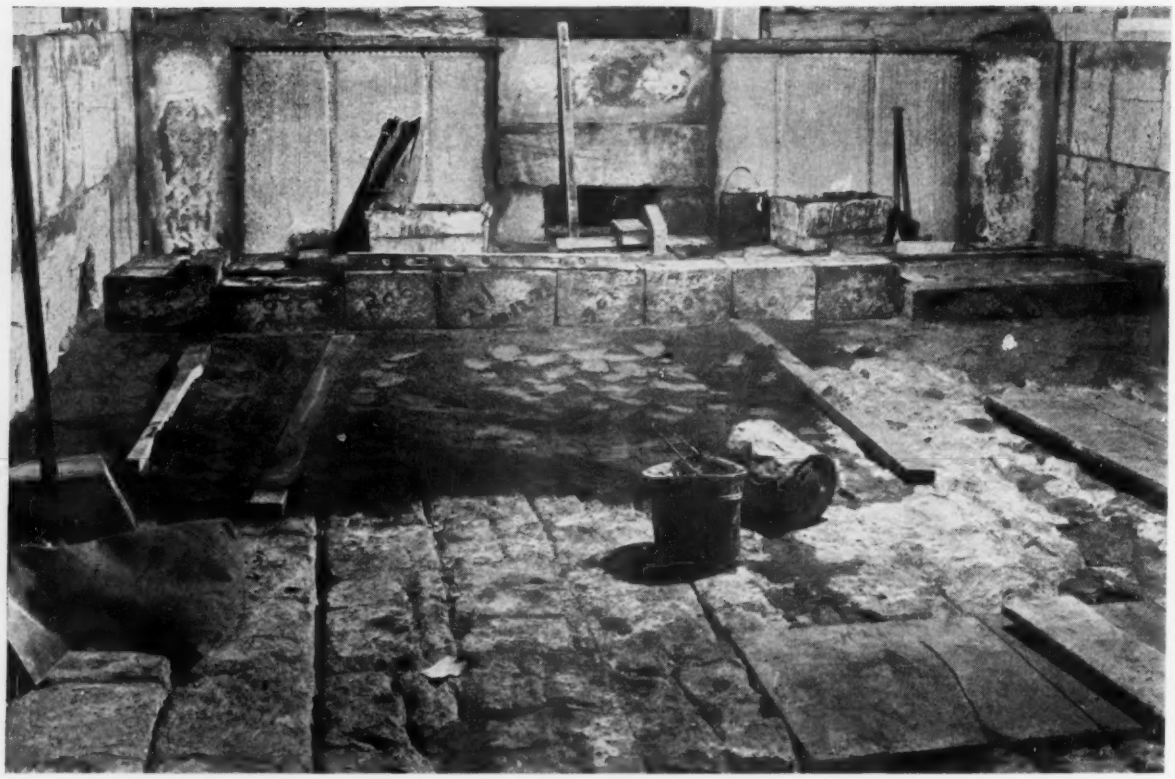

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A Monthly Publication Devoted to Proceedings of The Society and Promotion of Cooperative Research of Technical, Scientific, and Art Questions
Volume 20 NOVEMBER, 1941 Number 11

# PAPERS

## SYMPOSIUM ON COLOR STANDARDS AND MEASUREMENTS, I–V*

WOLDEMAR A. WEYL, *Chairman*

## I, METHODS OF DESIGNATING COLOR

BY DEANE B. JUDD

ABSTRACT

The topics discussed are definition or ideas of color, attributes of color perception, modes of appearance of object colors, limitations of color standards, and tristimulus specifications.

### I. Definition of Color

This brief discussion of color designation will start by mentioning a few things which have been called color but which are not color. The writer has been told that a ceramist makes use of a ceramic stain to produce vitreous coatings of nearly any desired color. The ceramic stain, which is sometimes called a color but is not really a color, is a colorant or a color-producing material. A plaque of vitreous enamel, which is called a color but is not really a color, is a specimen possessing color. The physicist says, "Let me measure the color of the specimen. I will give you a spectrophotometric curve of it; the spectrophotometer is the only true color analyzer." The spectrophotometer, however, does not measure color; it measures the reflecting properties of the specimen which are the primary determinants of its color and thus does not measure the color itself. Color is not a stain, a specimen, or a spectrophotometric curve.

At this point, it would be appropriate no doubt to state what color is, but unfortunately it is not possible to give one single definition of color. There are two important ideas that must be referred to by the name of color not only in the present paper but also in the more detailed discussions which follow. One idea of color is that of the ultimate consumer, the other is that of the manufacturer. The idea of color of the consumer is just what the eye sees; it has nothing to do with standards. The idea of color of the manufacturer is the property that can be controlled by color standards, which is the only practical view that he may take.

The whole problem of designating color arises from the conflict between the ideas of color of these two groups. If the manufacturer could guarantee by application of color standards that his product would yield the color perception desired by the ultimate consumer, these ideas would then no longer be in conflict. The papers in this Symposium will trace the methods of practical color standardization by means of which this ideal may be approached.

This introductory sketch of methods of designating color begins, therefore, with a method that arises entirely without recourse to color standards.

Imagine a man in a place where there are no spectrophotometers or color standards of any kind (for example, on a desert isle). A trunk full of hundreds of colored ceramic plaques of a wide variety of colors floats to the beach on a raft. How would such a castaway arrange these colors?

### II. Attributes of Color Perception

First, he spreads them out on the sand to look at them, and he finds a purely chance arrangement or disorder. Then he notices that a certain group of the plaques lacks an important characteristic possessed by the others; that is, some of the plaques lack *hue*. He separates the plaques into two groups according to perceived color, (1) a group of chromatic colors or those that possess hue, and (2) a group of achromatic (gray) colors or those that do not possess hue. The achromatic plaques may be arranged in a single series, ranging from black at the bottom through a series of dark grays, middle grays, and light grays to white at the top; this series varies only in *lightness*. For each chromatic plaque, moreover, he notes that a gray of the same lightness is present, which he calls the equivalent gray.

* The papers included in this Symposium were presented at the Forty-Third Annual Meeting, The American Ceramic Society, Baltimore, Md., March 31, 1941; they were received July 7, 1941.

He sorts out then the chromatic plaques, putting all of the reds together, then the yellows, greens, and blues. He also notes that there are others falling intermediate to these groups so that a whole circle can be set up, each part of which differs from its neighboring part by only a small step. This classification is according to *hue*.

Some of the plaques of a given hue, of course, are perceived to have dark colors whereas others are light (he has already noticed this fact by comparison with the lightness scale of grays). By sorting out all plaques of the same hue (red) and lightness (medium lightness), he discovers that there are still other variations. This mode of variation, which is more subtle than the other attributes, is called *saturation*, and he finds that saturation supplies the basis for his first step toward order. For achromatic colors (black, grays, and white) saturation is zero; for chromatic colors, it is greater than zero. Saturation, therefore, is proportional to the color departure from the equivalent gray.

Because there are three attributes of object-color, the hypothetical desert islander finds that he cannot put all of the specimens in a single plane arrangement and still keep them in order. He can make an orderly arrangement of all plaques of the same lightness, however, and so he divides them into groups, each group of about the same lightness. He then arranges each group separately, and by placing the darkest plaques on a disk, the next lighter group on a higher disk, as in a layer cake, he builds up a solid representation of all three attributes of color perception.

*Lightness* is represented by distance above the base plane; *hue*, by angle about the central or black-gray-white axis; and *saturation*, by distance from the axis. This space representation, in which each point represents the perception of a color, is called a color solid.

## III. Modes of Appearance of Object Colors

If this lonely color expert had found the trunk filled, not with ceramic plaques but with small specimens of transparent glass of various colors, he would proceed just as he did with the enameled plaques and would arrive at exactly the same attributes of color perception for transparent volumes as he did for opaque surfaces. He can describe the difference between the colors of any two of the glass specimens in terms of hue, lightness, and saturation just as aptly as that between the colors of two papers. There is one distinguishing mark, however, in the color solid for transparent volumes. The topmost point in the solid (occupied by white in the solid representing the colors perceived as belonging to surfaces) is now occupied by a color perception known paradoxically as colorless (see Fig. 1). This is the name by which the color perceived as belonging to perfectly clear nonlight-absorbing plastics, glasses, or crystals has come to be known.

## IV. Limitations of Color Standards

The definition of color of the ultimate consumer has been shown to lead to the two object-color solids in which each point represents a single color perception characterized by its particular hue, lightness, and saturation.[1] The measurement of the color of a given object might be supposed to consist merely of locating the proper point in the appropriate color solid. There are several reasons, however, why this will not work. (1) Hue, lightness, and saturation are qualities determined by visual estimate only, without any reference to standards of color. Such estimates are therefore much too imprecise to control the color of ceramic materials; (2) no two observers would get the same result, and gross discrepancies would be frequent; and (3) (by far the worst), each object has not one but many colors.

One well-known way of changing the color perceived to belong to an object is to change the spectral composition of the illuminant. The desert islander would not be greatly concerned with this source of error unless he tried to check his results by light from a campfire. If he obtained by that light an estimate of hue, lightness, and saturation for some one plaque too different from his daylight estimates to be accounted for by the uncertainty of his estimates, he would probably say, "Oh well, the color by campfire is not the true color; the daylight color is the one that really counts." The problem of the color of ceramic materials cannot be disposed of that way because the ultimate consumer may never view certain kinds of ceramic ware by daylight. It can be solved only by applying the color standard separately for each illuminant.

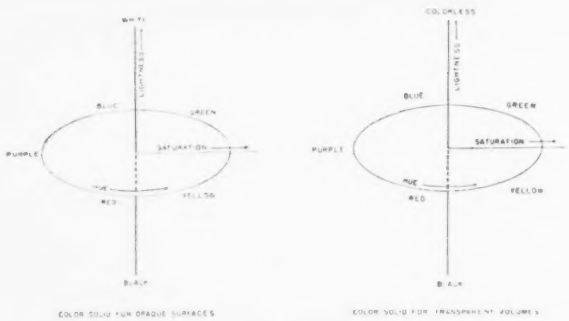


FIG. 1.—Dimensions of the solids representing the color perceptions of objects. Although the solid figure for opaque surfaces and that for transparent volumes have the same dimensions, lightness for surfaces varies from black to white whereas lightness for transparent volumes varies from black to colorless.

There is another source of error, less well recognized, which has crept into the technique of the imaginary desert islander. These plaques were viewed against the background formed by sand on the beach, but this sand might be nearly white, formed by fine particles of quartz, or nearly black sand, formed by coarse particles of basalt. It would make a good deal of difference, particularly in the estimates of lightness of the plaques, which kind of sand happened to form this beach. A gray plaque, which he has estimated to be about halfway in lightness between black and white when viewed against the background of white sand would be perceived to have a lightness much closer to that of white

[1] D. B. Judd, "Color Systems and Their Inter-Relation," *Trans. Illum. Eng. Soc.*, **36** [3] 336–69 (1941).

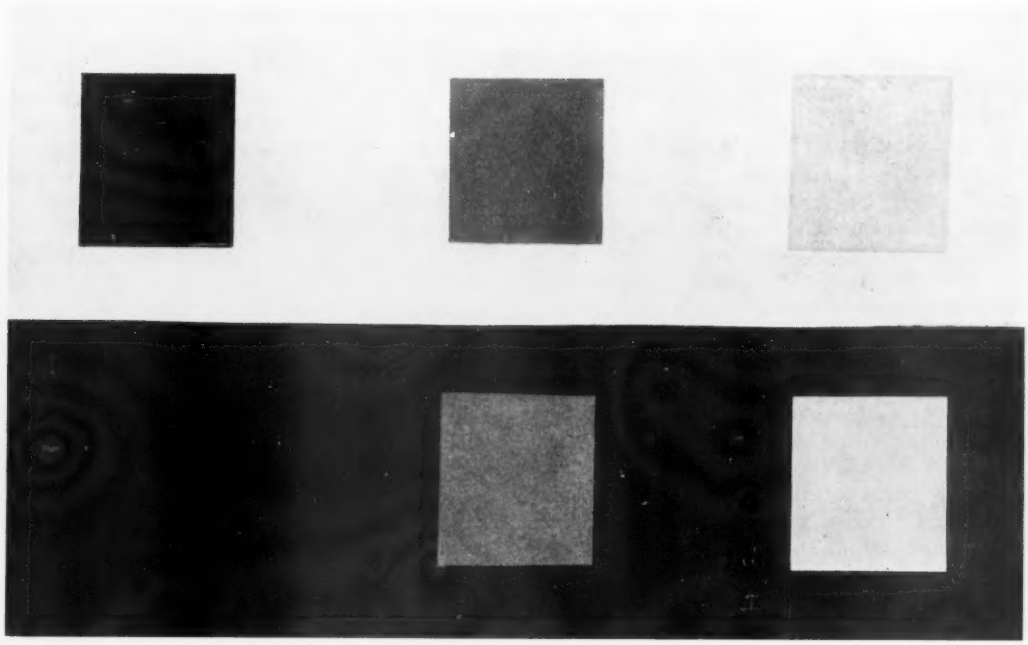

FIG. 2.—Influence of background on lightness of surface-color perceptions. The two gray rectangles have nearly the same apparent reflectance, but the one on the dark gray background is perceived to be much lighter than the one on the white background.

if it were viewed against a background of black sand. The estimate might easily change from a lightness of 40 to one of 60% (Fig. 2). The color, therefore, perceived to belong to a given object depends importantly on the colors of the surroundings.

These facts are well known to the designer and manufacturer of ceramic ware, and some attempt has been made to evaluate them quantitatively,[2] but the colorimetrists have not yet discovered how to take account of them in any practical system of color specification.

Two distinct ways to obtain useful color specifications, however, are (1) by matching the specimen with a known material standard of color similarly illuminated and viewed and (2) by matching the light reflected or transmitted by the specimen with a known standard of light.

Specification by material standards of color is widely practiced and avoids any difficulty from the effect of surroundings because the specimen and standard undergo the same color changes. The color match set up between specimen and standard, however, may depend importantly on the illuminant by which they are compared. Such standards are discussed by Robertson.[3]

Color specification by standards of light is practiced less widely, but it has been the subject of considerable recent study not only in ceramics but in other fields. Comparisons between specimens and standards of this sort are not usually made by real observers but by a hypothetical standard observer, whose characteristics are applied by computation to the specimen after spectrophotometric analysis. This method eliminates the difficulty of the change of color of a specimen with different illuminants because these computations may be carried out for any illuminant of known spectral composition if the information is considered to be worth the trouble. The results of these computations may be converted into terms that correlate reasonably well with the attributes of color perception, namely, hue, lightness, and saturation. The most common method of reducing these data gives fairly good correlation with the color perceived to belong to the specimen when it is viewed with dark surroundings. If the specifications of the specimens are considered in relation to those for the illuminant,[4] there is good correlation with the color perceived when the specimen is viewed on a white ground.

Neither material standards of color nor light standards, therefore, serve perfectly to estimate color according to the idea of the consumer. Neither method

[2] (*a*) E. Q. Adams and P. W. Cobb, "Effect on Foveal Vision of Bright (and Dark) Surroundings," *Jour. Expll. Psychology*, **5** [1] 39–45 (1922).
(*b*) D. B. Judd, "Hue, Saturation, and Lightness of Surface Colors with Chromatic Illumination," *Jour. Research Nat. Bur. Stand.*, **24** [3] 293–333 (1940); *Jour. Optical Soc. Amer.*, **30** [1] 2–32 (1940); *Ceram. Abs.*, **19** [7] 175 (1940).
(*c*) S. M. Newhall, "Preliminary Report of the O.S.A. Subcommittee on the Spacing of the Munsell Colors," *Jour. Optical Soc. Amer.*, **30** [12] 617–45 (1940); p. 628; *Ceram. Abs.*, **20** [3] 63 (1940).

[3] See paper No. III by Campbell Robertson, this issue, pp. 385–86.

[4] H. E. Ives, "Relation Between Color of Illuminant and Color of Illuminated Object," *Trans. Illum. Eng. Soc.*, **7** [2] 62–72 (1912).

can evaluate what the observer will see as the color of the specimen in every conceivable viewing situation, but they both give useful appraisals of appearance of the specimen in ordinary circumstances.

## V. Color Specification by Combinations of Lights

These color standards, made up of combinations of lights, lead to specifications that may be evaluated directly by photoelectric means,[5] and these specifications permit a convenient expression of color tolerances, which are discussed by Balinkin.[6] A preliminary discussion, however, of this kind of color standards is given here.

Two methods are used to specify color by a combination of standard lights as follows: (1) by color match with an additive combination of three fixed lights or primaries, and (2) by color match with an additive combination of two lights: one fixed, such as daylight; and the other variable, such as the various parts of the spectrum. The first method, called tristimulus specification, is important because it permits the reduction of spectrophotometric data. The best-known example of the fixed-light, variable-light method is by the use of dominant wave length and purity[1]; this method is important because it yields variables which correlate to a degree with the attributes of color perception, namely, hue and saturation. The fixed light, which is usually the same as the illuminant, is represented by the origin of a system of polar coordinates. Tristimulus specifications may be converted into dominant wave length and purity.

[5] See paper No. IV by R. M. Robertson and L. H. Milligan, this issue, pp. 387–91.

[6] See paper No. V by I. A. Balinkin, this issue, pp. 392–402.

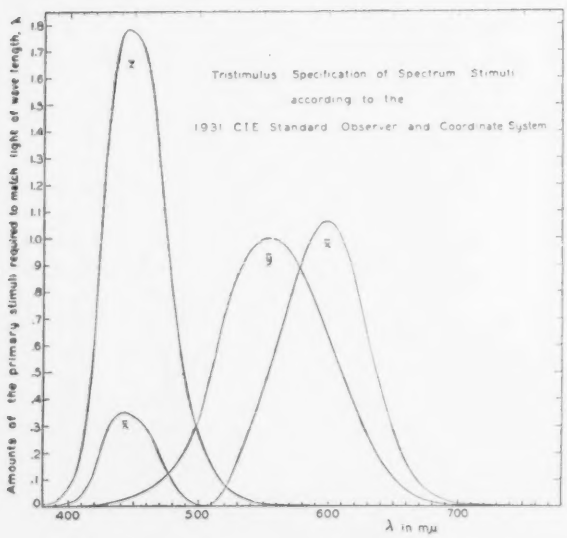


FIG. 3.—Tristimulus specifications of the equal-energy spectrum according to the 1931 I.C.I. (or C.I.E.) standard observer and coordinate system for colorimetry. These specifications are used to compute from spectrophotometric data the tristimulus specification of an opaque surface or a transparent volume for any illuminant of known spectral composition (see also Table I).

### (1) Tristimulus Specification

Three lights are required in an additive mixture to color-match the beam of light leaving an object. The amounts of the three fixed lights or primaries constitute the specification. If the photometric field is illuminated by two components whose tristimulus specifications are $X_1$, $Y_1$, and $Z_1$, and $X_2$, $Y_2$, and $Z_2$, respectively, the specification of the resultant is simply $X_1 + X_2$, $Y_1 + Y_2$, $Z_1 + Z_2$, that is, the resultant is obtained by simple addition. The same principle, of course, applies to additive combinations of any number of lights. This simple law has been repeatedly verified for a large middle range of brightnesses. When it is recalled, therefore, that any light may be considered to be the sum of the various parts of its spectrum, the color specification corresponding to any spectrophotometric curve obviously may also be computed by simple addition. The tristimulus specifications of each part of the spectrum of course must be known. These specifications differ somewhat from observer to observer, and, with trivial exceptions, they may be given for any triad of primaries. It is almost universal practice, however, to use tristimulus specifications of the equal-energy spectrum according to the standard observer and primaries recommended in 1931 by the International Commission on

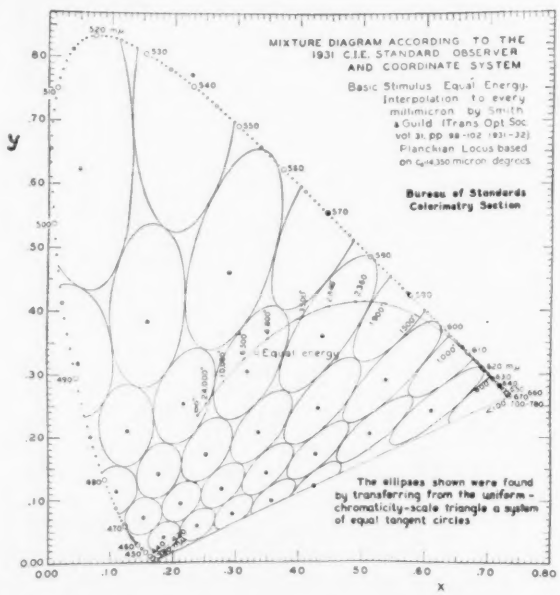


FIG. 4.—The $(x, y)$ plot, known as the chromaticity or mixture diagram of the 1931 I.C.I. (or C.I.E.) colorimetric coordinate system. The chromaticity of any color is represented by a point on this diagram. If the color is produced by a mixture of two other colors, the chromaticity of the mixture is represented on the straight line connecting the points representing the chromaticities of the component colors. The chromaticities of the spectrum are indicated by small circles; all others are represented by points within the area bounded by the spectrum locus and the straight line joining its extremes. The family of ellipses indicates approximately the departure of the I.C.I. chromaticity scales from perceptual uniformity; this family was derived from the uniform-chromaticity-scale system (see Fig. 5).

Illumination.[7] These specifications ($\bar{x}$, $\bar{y}$, $\bar{z}$) are given in Table I and are illustrated in Fig. 3.

There is a great advantage in having all colorimetric specifications given in the same system so that they are immediately comparable. The coordinate system chosen, furthermore, which has advantages in routine computation, has been adopted in the United States, Great Britain, France, and Germany, and its use is constantly spreading.

The outstanding disadvantage of this colorimetric system is that the specifications resulting from it fail to suggest the color perception readily. It is nearly always necessary to make use of a map showing colorimetric landmarks, such as the various parts of the spectrum. This is done by use of a chromaticity (or mixture) diagram obtained by plotting $X/(X+Y+Z)$ against $Y/(X+Y+Z)$ (Fig. 4). These fractions are called trilinear coordinates or trichromatic coefficients and are designated ($x$, $y$, $z$), the $z$-coordinate being an abbreviation for $Z/(X+Y+Z)$. Table I gives the trichromatic coefficients of the spectrum. By plotting a point ($x$, $y$) on such a chromaticity diagram or map to represent a specimen, the chromaticity relationship with other specimens is made clear.

An effort has been made recently to supplement the standard coordinate system by choice of other primaries which yield a chromaticity spacing of colors more in accord with that in the constant-lightness planes of the color solid. Such systems, known as uniform-chro-

[7] (*a*) Proceedings of Eighth Session, Commission Internationale de l'Eclairage, Cambridge, England, pp. 19–29 (Sept., 1931).
(*b*) D. B. Judd, "The 1931 I.C.I. Standard Observer and Coordinate System for Colorimetry," *Jour. Optical Soc. Amer.*, **23** [10] 359–74 (1933); *Ceram. Abs.*, **13** [8] 198 (1934).
(*c*) A. C. Hardy, Handbook of Colorimetry. Massachusetts Institute of Technology Press, Cambridge, Mass., 1936. 85 pp.

TABLE I
THE 1931 I.C.I. STANDARD OBSERVER

| Trichromatic coefficients | | | Wave length | Tristimulus specifications of equal-energy spectrum | | | Trichromatic coefficients | | | Wave length | Tristimulus specifications of equal-energy spectrum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $x$ | $y$ | $z$ | (mμ) | $\bar{x}$ | $\bar{y}$ | $\bar{z}$ | $x$ | $y$ | $z$ | (mμ) | $\bar{x}$ | $\bar{y}$ | $\bar{z}$ |
| 0.1741 | 0.0050 | 0.8209 | 380 | 0.0014 | 0.0000 | 0.0065 | 0.5125 | 0.4866 | 0.0009 | 580 | 0.9163 | 0.8700 | 0.0017 |
| 0.1740 | 0.0050 | 0.8210 | 385 | 0.0022 | 0.0001 | 0.0105 | 0.5448 | 0.4544 | 0.0008 | 585 | 0.9786 | 0.8163 | 0.0014 |
| 0.1738 | 0.0049 | 0.8213 | 390 | 0.0042 | 0.0001 | 0.0201 | 0.5752 | 0.4242 | 0.0006 | 590 | 1.0263 | 0.7570 | 0.0011 |
| 0.1736 | 0.0049 | 0.8215 | 395 | 0.0076 | 0.0002 | 0.0362 | 0.6029 | 0.3965 | 0.0006 | 595 | 1.0567 | 0.6949 | 0.0010 |
| 0.1733 | 0.0048 | 0.8219 | 400 | 0.0143 | 0.0004 | 0.0679 | 0.6270 | 0.3725 | 0.0005 | 600 | 1.0622 | 0.6310 | 0.0008 |
| 0.1730 | 0.0048 | 0.8222 | 405 | 0.0232 | 0.0006 | 0.1102 | 0.6482 | 0.3514 | 0.0004 | 605 | 1.0456 | 0.5668 | 0.0006 |
| 0.1726 | 0.0048 | 0.8226 | 410 | 0.0435 | 0.0012 | 0.2074 | 0.6658 | 0.3340 | 0.0002 | 610 | 1.0026 | 0.5030 | 0.0003 |
| 0.1721 | 0.0048 | 0.8231 | 415 | 0.0776 | 0.0022 | 0.3713 | 0.6801 | 0.3197 | 0.0002 | 615 | 0.9384 | 0.4412 | 0.0002 |
| 0.1714 | 0.0051 | 0.8235 | 420 | 0.1344 | 0.0040 | 0.6456 | 0.6915 | 0.3083 | 0.0002 | 620 | 0.8544 | 0.3810 | 0.0002 |
| 0.1703 | 0.0058 | 0.8239 | 425 | 0.2148 | 0.0073 | 1.0391 | 0.7006 | 0.2993 | 0.0001 | 625 | 0.7514 | 0.3210 | 0.0001 |
| 0.1689 | 0.0069 | 0.8242 | 430 | 0.2839 | 0.0116 | 1.3856 | 0.7079 | 0.2920 | 0.0001 | 630 | 0.6424 | 0.2650 | 0.0000 |
| 0.1669 | 0.0086 | 0.8245 | 435 | 0.3285 | 0.0168 | 1.6230 | 0.7140 | 0.2859 | 0.0001 | 635 | 0.5419 | 0.2170 | 0.0000 |
| 0.1644 | 0.0109 | 0.8247 | 440 | 0.3483 | 0.0230 | 1.7471 | 0.7190 | 0.2809 | 0.0001 | 640 | 0.4479 | 0.1750 | 0.0000 |
| 0.1611 | 0.0138 | 0.8251 | 445 | 0.3481 | 0.0298 | 1.7826 | 0.7230 | 0.2770 | 0.0000 | 645 | 0.3608 | 0.1382 | 0.0000 |
| 0.1566 | 0.0177 | 0.8257 | 450 | 0.3362 | 0.0380 | 1.7721 | 0.7260 | 0.2740 | 0.0000 | 650 | 0.2835 | 0.1070 | 0.0000 |
| 0.1510 | 0.0227 | 0.8263 | 455 | 0.3187 | 0.0480 | 1.7441 | 0.7283 | 0.2717 | 0.0000 | 655 | 0.2187 | 0.0816 | 0.0000 |
| 0.1440 | 0.0297 | 0.8263 | 460 | 0.2908 | 0.0600 | 1.6692 | 0.7300 | 0.2700 | 0.0000 | 660 | 0.1649 | 0.0610 | 0.0000 |
| 0.1355 | 0.0399 | 0.8246 | 465 | 0.2511 | 0.0739 | 1.5281 | 0.7311 | 0.2689 | 0.0000 | 665 | 0.1212 | 0.0446 | 0.0000 |
| 0.1241 | 0.0578 | 0.8181 | 470 | 0.1954 | 0.0910 | 1.2876 | 0.7320 | 0.2680 | 0.0000 | 670 | 0.0874 | 0.0320 | 0.0000 |
| 0.1096 | 0.0868 | 0.8036 | 475 | 0.1421 | 0.1126 | 1.0419 | 0.7327 | 0.2673 | 0.0000 | 675 | 0.0636 | 0.0232 | 0.0000 |
| 0.0913 | 0.1327 | 0.7760 | 480 | 0.0956 | 0.1390 | 0.8130 | 0.7334 | 0.2666 | 0.0000 | 680 | 0.0468 | 0.0170 | 0.0000 |
| 0.0687 | 0.2007 | 0.7306 | 485 | 0.0580 | 0.1693 | 0.6162 | 0.7340 | 0.2660 | 0.0000 | 685 | 0.0329 | 0.0119 | 0.0000 |
| 0.0454 | 0.2950 | 0.6596 | 490 | 0.0320 | 0.2080 | 0.4652 | 0.7344 | 0.2656 | 0.0000 | 690 | 0.0227 | 0.0082 | 0.0000 |
| 0.0235 | 0.4127 | 0.5638 | 495 | 0.0147 | 0.2586 | 0.3533 | 0.7346 | 0.2654 | 0.0000 | 695 | 0.0158 | 0.0057 | 0.0000 |
| 0.0082 | 0.5384 | 0.4534 | 500 | 0.0049 | 0.3230 | 0.2720 | 0.7347 | 0.2653 | 0.0000 | 700 | 0.0114 | 0.0041 | 0.0000 |
| 0.0039 | 0.6548 | 0.3413 | 505 | 0.0024 | 0.4073 | 0.2123 | 0.7347 | 0.2653 | 0.0000 | 705 | 0.0081 | 0.0029 | 0.0000 |
| 0.0139 | 0.7502 | 0.2359 | 510 | 0.0093 | 0.5030 | 0.1582 | 0.7347 | 0.2653 | 0.0000 | 710 | 0.0058 | 0.0021 | 0.0000 |
| 0.0389 | 0.8120 | 0.1491 | 515 | 0.0291 | 0.6082 | 0.1117 | 0.7347 | 0.2653 | 0.0000 | 715 | 0.0041 | 0.0015 | 0.0000 |
| 0.0743 | 0.8338 | 0.0919 | 520 | 0.0633 | 0.7100 | 0.0782 | 0.7347 | 0.2653 | 0.0000 | 720 | 0.0029 | 0.0010 | 0.0000 |
| 0.1142 | 0.8262 | 0.0596 | 525 | 0.1096 | 0.7932 | 0.0573 | 0.7347 | 0.2653 | 0.0000 | 725 | 0.0020 | 0.0007 | 0.0000 |
| 0.1547 | 0.8059 | 0.0394 | 530 | 0.1655 | 0.8620 | 0.0422 | 0.7347 | 0.2653 | 0.0000 | 730 | 0.0014 | 0.0005 | 0.0000 |
| 0.1929 | 0.7816 | 0.0255 | 535 | 0.2257 | 0.9149 | 0.0298 | 0.7347 | 0.2653 | 0.0000 | 735 | 0.0010 | 0.0004 | 0.0000 |
| 0.2296 | 0.7543 | 0.0161 | 540 | 0.2904 | 0.9540 | 0.0203 | 0.7347 | 0.2653 | 0.0000 | 740 | 0.0007 | 0.0003 | 0.0000 |
| 0.2658 | 0.7243 | 0.0099 | 545 | 0.3597 | 0.9803 | 0.0134 | 0.7347 | 0.2653 | 0.0000 | 745 | 0.0005 | 0.0002 | 0.0000 |
| 0.3016 | 0.6923 | 0.0061 | 550 | 0.4334 | 0.9950 | 0.0087 | 0.7347 | 0.2653 | 0.0000 | 750 | 0.0003 | 0.0001 | 0.0000 |
| 0.3373 | 0.6589 | 0.0038 | 555 | 0.5121 | 1.0002 | 0.0057 | 0.7347 | 0.2653 | 0.0000 | 755 | 0.0002 | 0.0001 | 0.0000 |
| 0.3731 | 0.6245 | 0.0024 | 560 | 0.5945 | 0.9950 | 0.0039 | 0.7347 | 0.2653 | 0.0000 | 760 | 0.0002 | 0.0001 | 0.0000 |
| 0.4087 | 0.5896 | 0.0017 | 565 | 0.6784 | 0.9786 | 0.0027 | 0.7347 | 0.2653 | 0.0000 | 765 | 0.0001 | 0.0000 | 0.0000 |
| 0.4441 | 0.5547 | 0.0012 | 570 | 0.7621 | 0.9520 | 0.0021 | 0.7347 | 0.2653 | 0.0000 | 770 | 0.0001 | 0.0000 | 0.0000 |
| 0.4788 | 0.5202 | 0.0010 | 575 | 0.8425 | 0.9154 | 0.0018 | 0.7347 | 0.2653 | 0.0000 | 775 | 0.0000 | 0.0000 | 0.0000 |
| 0.5125 | 0.4866 | 0.0009 | 580 | 0.9163 | 0.8700 | 0.0017 | 0.7347 | 0.2653 | 0.0000 | 780 | 0.0000 | 0.0000 | 0.0000 |
| Totals | | | | | | | | | | | 21.3713 | 21.3714 | 21.3715 |

maticity-scale systems, have been proposed by Judd,[8] MacAdam,[9] Breckenridge and Schaub,[10] Scofield, Judd, and Hunter,[11] and Robertson and Milligan.[12] Several of these systems place achromatic colors at the origin of the coordinates of the chromaticity diagram, and two of them are adjusted so that the coordinate axes bear a simple relation to the unitary hues (red, yellow, green, and blue) of the color perceptions of the specimens under ordinary viewing conditions. An effort has thus been made to increase the correlation between the chromaticity diagram and the constant-lightness planes of the color solid. Figure 5 shows the Judd uniform-chromaticity-scale triangle. The ellipses (shown on Fig. 4) would be equal circles on this triangle and would therefore indicate the scale of perceptibility for the various parts of the chromaticity diagram of the standard I.C.I. system.[8(c)] If the use of the improved spacing, choice of origin, and orientation of axes of uniform-chromaticity-scale diagrams is shown to be of practical importance, color specifications may be increasingly given not only according to the standard system but also by some uniform-chromaticity-scale system. Attempts to explore the practical advantages of such alternate color systems should be encouraged.

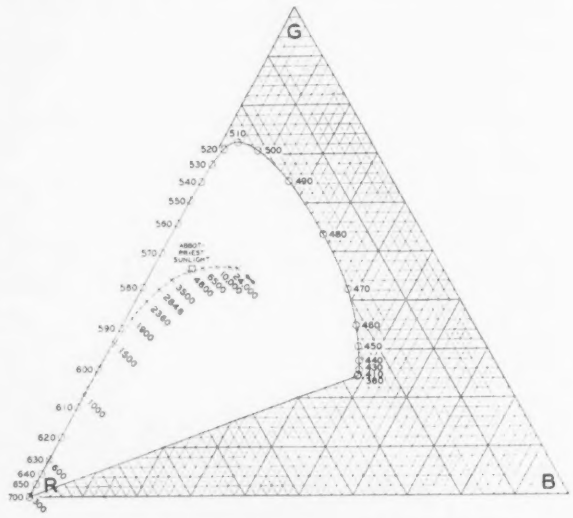


FIG. 5.—The uniform-chromaticity-scale triangle according to Judd. The family of ellipses (Fig. 4) would be a family of equal tangent circles on this triangle. Other systems with similar chromaticity spacing have been proposed by MacAdam, Breckenridge and Schaub, Scofield, Judd, and Hunter, and Robertson and Milligan.

## VI. Conclusions

In conclusion, it may be repeated that, to the ultimate consumer, color is what the eye sees; to the manufacturer, it is the property controlled by color standards. The chief ideas basic to the designation of color have been reviewed to prepare the ground for the more detailed discussions which follow.

NATIONAL BUREAU OF STANDARDS
WASHINGTON, D. C.

[8] (*a*) D. B. Judd, "Chromaticity Sensibility to Stimulus Differences," *Jour. Optical Soc. Amer.*, **22** [2] 72–108 (1932).

(*b*) D. B. Judd, "A Maxwell Triangle Yielding Uniform Chromaticity Scales," *Jour. Research Nat. Bur. Stand.*, **14** [1] 41–57 (1935); R.P. 756; *Jour. Optical Soc. Amer.*, **25** [1] 24–35 (1935); *Ceram. Abs.*, **14** [4] 86 (1935).

(*c*) D. B. Judd, "Estimation of Chromaticity Differences and Nearest Color Temperature on the Standard 1931 I.C.I. Colorimetric Coordinate System," *Jour. Research Nat. Bur. Stand.*, **17** [5] 771–79 (1936); R.P. 944; *Jour. Optical Soc. Amer.*, **26** [11] 421–26 (1936); *Ceram. Abs.*, **16** [2] 76 (1937).

[9] D. L. MacAdam, "Projective Transformations of I.C.I. Color Specifications," *Jour. Optical Soc. Amer.*, **27** [8] 294–99 (1937).

[10] F. C. Breckenridge and W. R. Schaub, "Rectangular Uniform-Chromaticity-Scale Coordinates," *Jour. Optical Soc. Amer.*, **29** [9] 370–80 (1939).

[11] F. Scofield, D. B. Judd, and R. S. Hunter, "Proposed Method for Designating Color," *ASTM Bull.*, No. 110, pp. 19–24 (1941).

[12] See pp. 387–91, this issue.

# II, SPECTROPHOTOMETRY OF CERAMIC MATERIALS

By Fred H. Emery

Abstract

Spectrophotometry is of value in the study of ceramic materials not only in providing data which may be transformed to tristimulus specifications of color, but which will also indicate the chemical nature of the colorants used. The distinction between perfect and "drifting" color matches is shown by spectrophotometric curves. An example of the use of the spectrophotometer in opacifier research is given. Various color notation systems are outlined, and an example is given of the use of Adams' uniform chromaticity system. The method is sufficiently rapid for routine color control.

## I. Introduction

Spectrophotometry may be considered fundamentally as an extension of visual matching. Various methods are used in matching colors as follows: (1) The samples may be observed in whatever daylight happens to be available at the point where the panels are located; (2) a standard lamp for matching may be used; (3) two different but standard light sources may be used to determine which of the two panels is lighter; and (4) colors may be matched by determining which panel is lighter when it is illuminated by all of the pure spectrum colors distinguishable in the rainbow.

## II. Types of Spectrophotometers

The last method, which is too tedious to be carried out manually on a visual spectrophotometer, is commonly done on one of the several automatic recording spectrophotometers[1] on the market. The Hardy spectrophotometer[2] draws curves automatically to show the relative lightness or reflectance of a pair of samples as they would appear if illuminated with thirty pure spectrum colors, from violet to red, inclusive. This is actually done for each sample by automatically adjusting the monochromatic light reflected from a standard magnesium oxide white to match the amount of the same light reflected by the sample. Figure 1 gives curves showing two porcelain enamel whites.

These instruments are satisfactory, but they are complicated and expensive. An expensive spectrophotometric instrument is necessary for reflectance measurements, but when transmission measurements only are required, equipment[3] costing around $500 can be made to give satisfactory results. With these inexpensive spectrophotometers the curve is not drawn automatically but must be plotted point by point.

## III. Types of Color Matches

The two types of color matches are spectrophotometric and nonspectrophotometric. As shown in Figs. 1 and 2, spectrophotometric matches are generally chemical matches and show parallel curves whereas nonspectrophotometric matches do not. When a given color is fired into the same glaze in the same way, the same curve will always be obtained. Two samples which give the same spectrophotometric curve will be a perfect color match.

In a nonspectrophotometric match shown in Fig. 2, curve *A* is a synthetic resin white, whereas curve *B* is a porcelain enamel match. The visual difference between these two samples will change when they are viewed under different illuminants. These samples constitute a "drifting" color match. The samples will be a poorer match in daylight than in artificial tungsten illumination because of the relatively greater amount of blue light in daylight than in tungsten light and because of the greater difference of the two samples in the blue wave lengths. The spectrophotometer is useful in proving that the matches submitted are perfect rather than drifting. These samples were obtained about one year ago, and judging from the improved matches that are now available between synthetic resin whites and porcelain enamel whites, the spectrophotometer has been used to verify the progress of experiments designed to straighten the curve of the synthetic resin white.

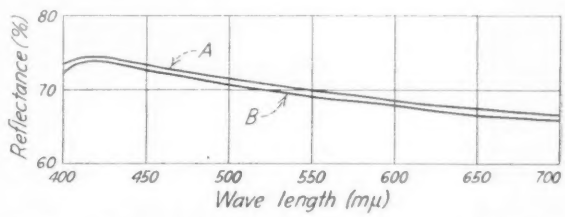


Fig. 1.—Spectrophotometric match; curve *A*, synthetic opacifier; curve *B*, tin oxide opacifier.

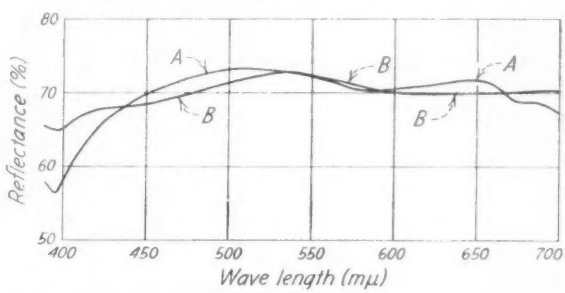


Fig. 2.—Nonspectrophotometric match; curve *A*, synthetic resin white; curve *B*, porcelain enamel white.

[1] A. E. Parker, Spectrophotometry and Color Evaluation, pp. 47–59. Symposium on Color. Amer. Soc. Testing Materials, Philadelphia, Pa., 1941.

[2] (*a*) A. C. Hardy, "New Recording Spectrophotometer," *Jour. Optical Soc. Amer.*, **25** [9] 205–11 (1935).
(*b*) J. L. Michaelson, "Construction of General Electric Recording Spectrophotometer," *ibid.*, **28** [10] 365–71 (1938).

[3] W. F. Roeser, "New Instruments, Spectrophotometers," *Rev. Sci. Instruments*, **12** [5] 280–81 (1941).

The recording spectrophotometer was used in the development of a synthetic opacifier for a porcelain enamel. Figure 3, curve *C*, shows original attempts about five years ago, and the result is seen to be a high opaque yellow. Curve *A* is tin oxide, and curve *B* is the synthetic opacifier that was produced three years ago. Curves *A* and *B* are nonspectrophotometric color matches. Although curve *B* has a greater reflectance than curve *A*, the white represented by the latter curve will be preferred by most persons in the porcelain enamel industry. Research has been continued until porcelain enamel whites are now produced as shown in Fig. 1. The synthetic opacifier, *A*, is a spectrophotometric match for tin oxide, *B*, differing only by giving slightly higher reflectance.

A spectrophotometer may also be used to reduce a color to a numerical designation. Readings are taken at ninety selected wave lengths, thirty serving for each primary. The International Commission on Illumination[4] tristimulus values may be obtained from these readings, and visual reflectances, dominant wave lengths, and purity may easily be calculated. Equal distances between colors as recorded on the I.C.I. diagrams are not equal perceptible visual differences. This procedure is useful for permanent standardization of a color or for checking various color systems but it is too tedious to use as a routine color control.

[4] A. C. Hardy, Handbook of Colorimetry, pp. 5–13. Massachusetts Institute of Technology Press, Cambridge, Mass., 1936. 85 pp.

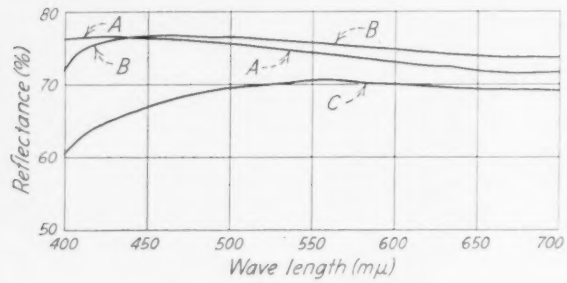


FIG. 3.

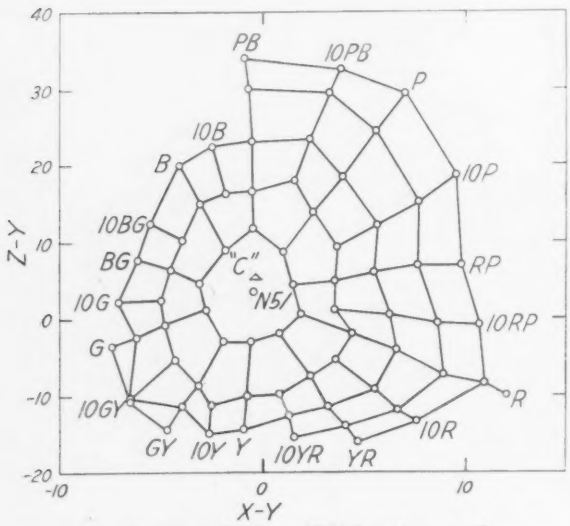


FIG. 4.—$X - Y$, $Z - Y$ (Adams' system).

Judd[5] and Adams[6] have developed uniform chromaticity systems of color notation wherein equal distances between colors as plotted are equal perceptual visual differences. The following results are based on Adams' uniform chromaticity system. Figure 4 is taken from the report of the Optical Society of America.[7] Each point represents a Munsell color chip as given by Munsell[8] for value 5. Spectrophotometric data and the I.C.I. tristimulus values, *X*, *Y*, and *Z*, used for the plot in Fig. 4 were obtained from the Munsell colors by Glenn and Killian.[9]

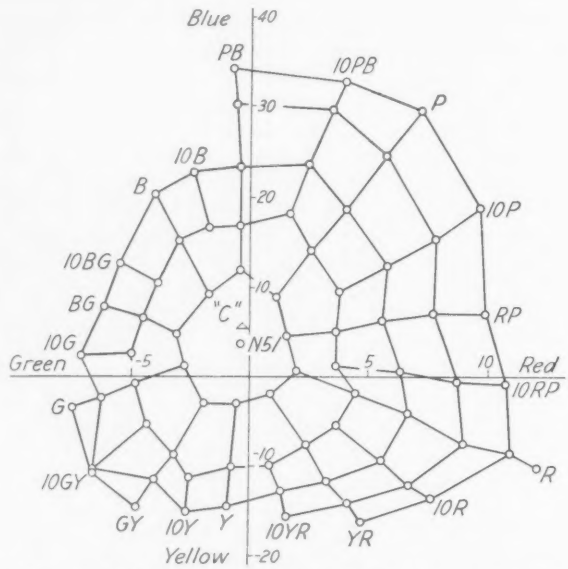


FIG. 5.—Red, green, and blue system; horizontal axis equals red minus green; vertical axis equals blue minus green.

Adams' system may be modified so that *X*, *Y*, and *Z* are designated as colors as follows: *X* is called "red"; *Y*, "green"; and *Z*, "blue." The coordinate axes are redrawn through the origin which represents neutral or achromatic colors (Fig. 5). If "red" minus "green" (or $X - Y$) is positive, the color is on the reddish side; if the difference is negative, the color is on the greenish side. Similarly, if "blue" minus "green" ($Z - Y$) is positive, the color is on the bluish side; if it is negative, it is on the yellowish side. If "red" minus "green" is positive and "blue" minus "green" is positive, the color

[5] D. B. Judd, "Maxwell Triangle Yielding Uniform Chromaticity Scales," *Jour. Optical Soc. Amer.*, **25** [1] 24–35 (1935); R.P. 756; *Ceram. Abs.*, **14** [4] 86 (1935).

[6] E. Q. Adams, "X–Z Planes in 1931 I.C.I. System of Colorimetry," *Jour. Optical Soc. Amer.*, **30** [12] 657A (1940).

[7] S. M. Newhall, "Preliminary Report of O.S.A. Subcommittee on Spacing of Munsell Colors," *ibid.*, **30** [12] 617–45 (1940); *Ceram. Abs.*, **20** [3] 63 (1941).

[8] Munsell Book of Color, "Chart for Value 5." Munsell Color Co., Baltimore, Md., 1929.

[9] J. J. Glenn and J. T. Killian, "Trichromatic Analysis of Munsell Book of Color," *Jour. Optical Soc. Amer.*, **30** [12] 609–16 (1940); *Ceram. Abs.*, **20** [3] 62 (1941).

is in the purple quadrant; and if "red" minus "green" is positive and "blue" minus "green" is negative, the color is in the orange quadrant. The differences between "red" and "green," and "blue" and "green" may readily be used to visualize the approximate appearance of a sample provided the reflectance of the sample is also known. The values of "red," "green," and "blue" may be considered to be the amounts of the selected three primaries, which when mixed would match the sample. The "red," "green," and "blue" readings may be the I.C.I. tristimulus values which are used by Adams. Selected counter-readings from a spectrophotometer or filter readings from an abridged spectrophotometer may also be used with certain limitations.

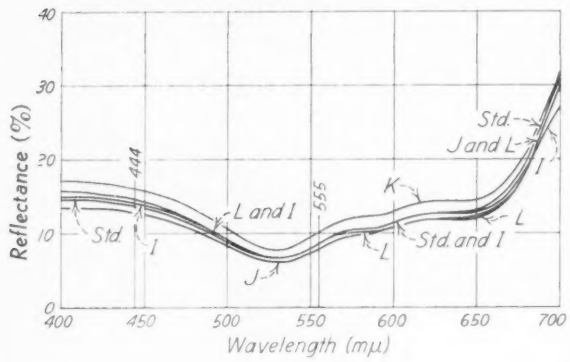


FIG. 6.

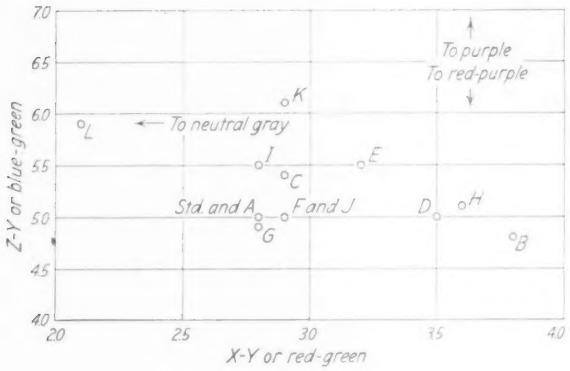


FIG. 7.—Reddish-purple series.

The adaptation of Adams' system described in this paper is suitable for routine use on samples which give parallel spectrophotometric curves. Three readings are taken from the curve or from the counter on the spectrophotometer. A reading taken at 444 mμ is used in place of the I.C.I. *Z* or "blue"; one taken at 555 mμ is used in place of the I.C.I. *Y* or "green"; and one taken at 600 mμ is used in place of I.C.I. *X* or "red." Green is subtracted from red and also from blue. The resulting differences are then plotted on a diagram similar to Fig. 5. The scale for blue minus green is made smaller than that of red minus green by a factor of 2.5.

The system is operated for routine color control as follows: The "red" minus "green," "blue" minus "green" value is determined for the standard, and the point is plotted. A series of samples similar to the standard but varying slightly in all directions is prepared and the "red" minus "green," "blue" minus "green" values are plotted for each sample. The difference between the "green" of the standard and the "green" of the various samples is also determined. The total difference between the point representing the standard and that representing a sample is then equal to the hypotenuse of a right triangle, one leg of which is the measured distance on the plot and the other the difference between the "green" value of the standard and that of the sample. In this way, the total color differences between the various samples of the group and the standard are determined and tabulated. The group of samples and the standard are then shown to all persons concerned in the manufacture, sale, and acceptance of the color, and an agreement is reached as to the color difference between the standard and the various samples. Because this system is a uniform chromaticity scale, an acceptable color unit will be found to be a certain factor of the tabulated color unit.

This method was tried on a group of twelve purple ceramic plaques that was compared to a purple standard. Figure 6 shows spectrophotometric curves from four of the samples. Readings were taken from the curves at 444, 555, and 600 mμ, and are recorded in

TABLE I

PURPLE GROUP

| Sample No. | Reflectance (%) At 444 mμ = "blue" | At 555 mμ = "green" | At 600 mμ = "red" | Blue-green | Red-green | Green* | Total difference |
|---|---|---|---|---|---|---|---|
| Standard | 13.6 | 8.6 | 11.4 | 5.0 | 2.8 | 0.0 | |
| *A* | 13.8 | 8.8 | 11.6 | 5.0 | 2.8 | +0.2 | 1.0 |
| *B* | 13.6 | 8.8 | 12.6 | 4.8 | 3.8 | +0.2 | 5.5 |
| *C* | 14.2 | 8.8 | 11.7 | 5.4 | 2.9 | +0.2 | 1.5 |
| *D* | 14.5 | 9.5 | 13.0 | 5.0 | 3.5 | +0.9 | 5.5 |
| *E* | 14.7 | 9.2 | 12.4 | 5.5 | 3.2 | +0.6 | 3.5 |
| *F* | 13.7 | 8.7 | 11.6 | 5.0 | 2.9 | +0.1 | 0.7 |
| *G* | 13.7 | 8.8 | 11.6 | 4.9 | 2.8 | +0.2 | 1.0 |
| *H* | 14.6 | 9.5 | 13.1 | 5.1 | 3.6 | +0.9 | 6.0 |
| *I* | 14.0 | 8.5 | 11.3 | 5.5 | 2.8 | −0.1 | 1.0 |
| *J* | 12.7 | 7.7 | 10.6 | 5.0 | 2.9 | −0.9 | 4.5 |
| *K* | 16.0 | 9.9 | 12.8 | 6.1 | 2.9 | +1.3 | 7.0 |
| *L* | 15.0 | 9.1 | 11.2 | 5.9 | 2.1 | +0.5 | 5.0 |

* Green of sample minus green of standard.

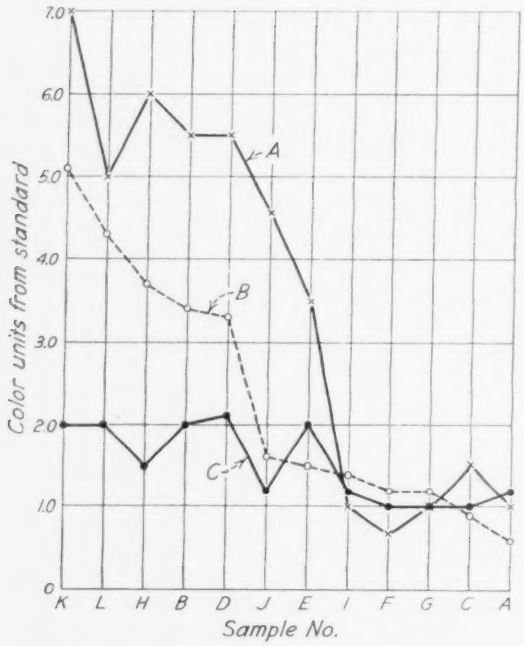


FIG. 8.—Color rating of reddish-purple series; curve *A*, computed from instrument readings; curve *B*, paint laboratory average; curve *C*, ceramic laboratory average.

Table I. The points representing the various samples are plotted on an enlarged portion of Adams' uniform chromaticity system shown in Fig. 7. The arrows indicate the direction to neutral gray, to purple, and to red-purple. The exact manner in which each of these samples differs from the standard may thus be determined. *L*, for example, is the dirtiest or weakest of the lot, and *B* is the cleanest as well as the reddest. The differences between the various standards may be determined by measurement on the chart. The total difference may be determined by considering the measured difference as one leg of a right triangle and the difference in "green" as the other. The hypotenuse then is the total difference. Total differences were computed for all of these colors by this method and compared with average visual ratings from a ceramic laboratory and from a paint laboratory. Color units are plotted against sample numbers. One color unit is considered as the greatest color difference that would be purchased as an acceptable color match. In Fig. 8, curve *A* is obtained from computed instrument readings; curve *B*, from the average of five paint matchers in a paint laboratory; and curve *C*, from the average of four color matchers in a ceramic laboratory. It may be said in general that the instrument agrees with the color matchers as well as they agree with each other. The discrepancy between *K* and *L* may be due to the fact that this method assumes the spectrophotometric curves to be parallel and that the curve for *L* deviates from this condition. The samples which differ the most are given a greater color difference by the instrument. This is to be expected as the eye is very sensitive to small differences, but it cannot easily evaluate large differences. The differences between the two laboratories may be attributed to the fact that purples are hard to match and that uniform conditions of illumination and viewing were not observed.

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# III, COLOR STANDARDS FOR OPAQUE CERAMIC MATERIALS

By Campbell Robertson

Abstract

The topics discussed are (1) the Munsell system and its arrangement of colors and the I.S.C.C.-N.B.S. method of designating colors and the possible uses of this method in ceramics, (2) the Maerz and Paul Dictionary, the Ostwald system, the British Color Council system, and others, and (3) the use of actual ceramic specimens as standards for color.

## I. Introduction

The preceding papers have discussed the design and use of different types of instruments for measuring the colors of opaque ceramic materials so that the colors may be described in usable numerical terms. Another general method of designating colors, either verbally or in writing, is by the use of standard color charts.

Everyone who has worked with colors has used or seen the various color charts that comprised the first systematic effort to place the description of colors on a uniform scientific basis. Color charts have been worked out in a number of forms; some of these are quite elaborate and complete and others are greatly simplified. Some had for their purpose the arrangement of all obtainable surface colors into systems based on the fundamental properties of color; other charts were designed for some specific practical application in commercial or industrial work. The use of these charts as a means to facilitate the transfer of color information is to be discussed in this paper. The discussion will be restricted to information relating to opaque colors, as of the broadest general interest, omitting the treatment of transmission colors.

There are several internationally outstanding color charts,[1] as well as dozens of minor ones that have been worked out for various purposes. Each of these charts consists of a collection of small color panels arranged systematically so that it is readily possible to locate the closest match on a chart to a given sample; these color panels are designated according to some numerical system so that one observer may transmit exact information to another as to what panel is referred to.

## II. Use of Color Charts

The possible use of a color chart for describing colored ceramic products is as follows. Each individual who is either conveying or receiving information about a shade of color must have a copy of the chart, and he must understand in advance that the chart is to be used as a reference. With this degree of preparation, a buyer, who wants to obtain a certain colored tile or enameled-steel sample with the least possible loss of time, may make his selection from a color chart in his office, either from the chart alone or by matching on the chart a colored sample that previously had been established as the desired shade. When he has determined which chart panel refers to the shade he wants, he may then give this information to a manufacturer, who is provided with a duplicate copy of the chart. He checks the shade, and, within a few minutes, he knows just what color is specified. The same procedure may even be carried several steps further; for example, the manufacturer, on looking at the sample, may find that it is a shade which is impossible to obtain under the necessary ceramic conditions. He may at once select the nearest practical shade that he would care to undertake to produce, look this up on the chart, and reply to the buyer, designating the chart panel that represents his best counter offer. It is readily possible to see the large saving in time that may be obtained. Colors may be referred to without ambiguity and without the delay incurred in mailing samples of actual materials.

## III. Limitations of Color Charts

This picture of the use of color charts, however, is not without its difficulties and limitations. Some of these limitations will be discussed in the form of questions which might be asked by someone who is considering the use of such a system. These questions are (1) is it possible to match any ceramic material with a chart panel and (2) how much special skill is required to use this method of color designation?

### (1) Matching Different Materials

There should be no difficulty in matching a given ceramic sample with a chart panel. Although the color panels in these charts are not made of ceramic materials (but rather inks or paints of various types) in practically all cases a desired color may be matched with satisfactory accuracy after a little practice in the use of the chart. The chief question here is how accurate the match must be and this also involves a question as to the size of the chart. The number of distinct colors distinguishable by a trained observer has been estimated to run up into very high figures (of the order of many millions). This variety of colors is obviously impractical as well as unnecessary for a chart, especially in the ceramic industry where the nature of the product and the firing operation make necessary a fairly wide tolerance. A specification,

[1] (*a*) Munsell Book of Color; standard ed., 37 charts; abridged ed., 22 charts. Munsell Color Co., Baltimore, Md., 1929.
(*b*) A. Maerz and M. R. Paul, Dictionary of Color. McGraw-Hill Publishing Co., Inc., New York, 1930. 207 pp., 56 color pp.
(*c*) J. S. Taylor, The Ostwald Color Album. Winsor and Newton, London, England, 1931.
(*d*) Ridgway, Color Standards and Color Nomenclature. Hoen, Baltimore, Md., 1912.

moreover, within too narrow a range could not be met. Of the principal systems mentioned, the Munsell charts include about 400 panels, the Maerz and Paul Dictionary contains about 7000, the Ostwald system about 600, and the Ridgway Dictionary about 1000. The more shades given on the chart, the closer it is possible to locate a certain shade but this likewise presents a more complicated problem.

It is obvious, therefore, that no matter what system is used, each chart panel represents in effect the midpoint of a small range of colors, and some interpolation between panels is always necessary. This necessity has possibly comprised the largest stumbling block (in the minds of users) in the use of color charts to specify colors. In nearly every case, however, the estimation of differences, in percentage, between an unknown color and the chart panel nearest to it may always be made with only a moderate amount of practice.

### (2) Special Skill in Use of Chart

The question of the skill required to use this method is solved after a little instruction is given in the use of the chart selected. This selection of colors requires adequate light and proper use of masks to shut out all panels except the one being compared. The observer must also be aware of the method of taking into account differences in gloss and depth in making such comparisons. With a few precautions, it is possible to use one of these systems smoothly and with practically no misunderstandings.

The use of color charts is an alternative method to the use of instrument data to transmit color information. Each method has its place, and the circumstances of a given case will determine which is the preferable system to use. Of the charts mentioned, the largest and most complete of any available in this country are those of Munsell[1(a)] and of Maerz and Paul.[1(b)]

## IV. Color-Solid System

A method of designating colors by simple names and modifiers has been worked out by Judd and Kelley[2] for the Inter-Society Color Council and the American Pharmaceutical Association. This method is not a chart but a set of divisions of the color-solid defined in terms of the Munsell system, with a name system carefully worked out to be mutually consistent with itself and as much as possible, with average actual usage. In this name system, the color-solid has been divided into 319 blocks, a number that seems to be adequate for most work. There is a possibility that a chart might be compiled in which the panels would indicate the approximate midpoints of the blocks represented by each designation of this system. Such a chart would have several advantages as a general utility system that would cover the range of surface colors in a convenient number of well-defined steps, accord well with accepted usage, and comprise an authoritative standard.

## V. Conclusions

Attempts have been made from time to time to set up color charts, which are composed of actual fired ceramic pieces instead of the printed or painted panels used in the charts that have been discussed. The use of fired ceramic pieces has some advantages, but there are also drawbacks as follows: (1) the excessive cost of making a substantial number of charts for this purpose and (2) the fact that there are so many diverse types of ceramic finishes that a chart prepared in one material, such as sheet-steel enamel, would not be a much better match for an overglaze or a body stained piece than the painted or inked charts.

In the use of or comparison with actual materials, the observer must always make allowances for gloss, depth of color layer, and other differences, which are too complicated to include in a chart and which must also be excluded even from instrument readings. The observer's skill, moreoever, must supplement any basic system that is used in order to realize the advantages of numerical methods of color designations.

[2] D. B. Judd and K. L. Kelly, "Method of Designating Colors," *Jour. Research Nat. Bur. Stand.*, **23** [3] 355–85 (1939); R.P. 1239; *Ceram. Abs.*, **19** [4] 85 (1940).

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# IV, A READILY VISUALIZED SYSTEM FOR MEASURING THE COLOR OF SURFACES

By Randal M. Robertson and Lowell H. Milligan

Abstract

A system of presenting color data in a form which can be readily visualized by the layman is proposed. Three color numbers are defined, a "Lightness number" and two chromaticity numbers called the "yellowness number" and "greenness number." Negative yellowness may be called blueness and negative greenness may be called purpleness. Chromaticities are thus represented on a plane in which rectangular axes correspond to the yellowness and greenness numbers, and in which the origin represents a neutral gray. Addition of a vertical Lightness number axis defines a color space in which all known colors make up a color solid.

These color numbers are defined in the paper in terms of the three values obtained using the Hunter reflectometer with tristimulus filters but they can be readily defined in other terms if the appropriate transformation is known. The relationship of the proposed system to other systems, particularly to Hunter's uniform chromaticity-scale system and to the Munsell system, is discussed. To a reasonably good approximation, the proposed system can be regarded as having a uniform chromaticity scale.

The original paper was given in the form of a dialogue, and in publication this form has been retained.

## I. Prologue

There are today several instruments, such as the spectrophotometer and the tristimulus colorimeter, by means of which color can be measured in terms of three numerical values. These results may be further expressed as the relative brightness and two chromaticity numbers, for example, I.C.I. (International Commission on Illumination) coefficients[1] or dominant wave length and excitation purity[1] or Hunter's coefficients, *alpha* and *beta*.[2]

From the point of view of the layman, however, little provision has been made for visualizing the colors represented by these values. The system to be described has been developed to express and to interpret color measurements in readily visualized form. The Hunter multipurpose reflectometer, with amber, green, and blue tristimulus filters, has been used to make the measurements.

The paper is presented in the form of a dialogue which simulates the conversation between a ceramic engineer (**L**) in charge of development and control work at his plant and one of his assistants (**R**) who has been assigned the task of studying the color of the product with the help of the Hunter multipurpose reflectometer.

## II. Dialogue

(Enter **R** with data sheet)

**R:** Here's the color data on that specimen: 0.201, 0.215, 0.210.

**L:** Whoa there! What does that mean? How can I visualize the *color* from those three numbers?

**R:** Why, those are the three reflectometer readings corresponding to the amber, green, and blue filters of our Hunter multipurpose reflectometer. I write them down in columns headed *A*, *G*, and *B*.

**L:** That's all very well, but is the color red, blue, tan, light, dark, or what? Isn't there some way I can form a picture of the color from those numbers?

**R:** Well, here's the specimen; you can look at it if you want to. But I thought that what we wanted was simply a way of recording color numerically such that any two colors which appear the same have the same numerical specifications and different colors have different specifications. That is what we have in these three numbers. What is more, we can set up standards for these three numbers, *A*, *G*, and *B*, together with allowable tolerance ranges. Isn't that enough?

**L:** No, it's not. I want to be able to form at least a rough picture of the color from the numerical data. Suppose you hadn't kept that specimen, how could I know from the data what color it was?

**R:** Well, for one thing, thanks to Mr. Hunter's careful choice of filters, the *G* value, which we get from our reflectometer, tells you whether the color is light or dark. It measures the luminous apparent reflectance or *brightness* of the color.

**L:** Just call it brightness, please.

**R:** The scale is from 0 to 1, corresponding to a variation from black to white; or we can multiply *G* by 100 and get a percentage figure, in which case 100% corresponds to white.

**L:** Let's do that. But still I can't tell whether the specimen is sky blue or pale pink.

**R:** You can get a *rough* idea by seeing whether the *A*, *G*, or *B* value predominates. Large *A* along with small *G* and *B* means red or yellow; large *G* along with small *A* and *B* means green, and so on.

[1] A. C. Hardy, Handbook of Colorimetry. Massachusetts Institute of Technology Press, 1936. 85 pp.

[2] (*a*) F. Scofield, D. B. Judd, and R. S. Hunter, "Proposed Method of Designating Color," *ASTM Bull.*, No. 110, pp. 19–24 (May, 1941); *Ceram. Abs.*, **20** [9] 212 (1941).

(*b*) R. S. Hunter, "Photoelectric Tristimulus Colorimetry." Published as part of the A.S.T.M.-I.S.C.C. Joint Symposium on Color, Its Specification and Use in Evaluating the Appearance of Materials, 1941 (may be obtained from The American Society for Testing Materials, 260 South Broad St., Philadelphia, Pa.).

**L:** That *is* a *rough* idea. Can't we put it on a numerical basis in terms that can be visualized at least approximately?

**R:** We can. We have defined brightness. Now what we want is two *chromaticity* numbers. I suggest that we transform our $A$, $G$, and $B$ values to I.C.I. tristimulus values using relations kindly supplied by Mr. Hunter. Then we will calculate the I.C.I. trichromatic coefficients and plot our color on an I.C.I. chromaticity diagram. It will then be child's play to determine the dominant wave length and excitation purity of the color. Let's do that.

**L:** (Who, during this outburst, has clasped his forehead, rolled his eyes, and loosened his collar.) Stop! Stop right there! *You* may be able to visualize something from that dominant-wave-length-purity business but *I* can't, and I don't think most people can. If you had said Purity, Body, and Flavor, then I *could* have visualized something—something that I'll need plenty of after *this* dialogue. And those big words which you tossed around so freely without definition: tristimulus, trichromatic. Isn't there some way of getting at this —uh—chromaticity without going into all that?

**R:** I'm afraid we'll have to get used to the word, "chromaticity," but maybe we can avoid the others for the time being. Now, Mr. Hunter defines two chromaticity numbers, $\alpha$ and $\beta$. I had a letter from him the other day saying that he is now using these values,[2]

$$\alpha = \frac{A - G}{A + 2G + B}$$

$$\beta = \frac{0.4(G - B)}{A + 2G + B}$$

where

$A$ is the reading with the amber filter of the reflectometer.
$G$ is the reading with the green filter.
$B$ is the reading with the blue filter.

We can use these; moreover, Mr. Hunter says that his system is a uniform chromaticity-scale system, meaning that equal distances on a graph of $\alpha$ versus $\beta$ correspond to equal visual differences no matter where they occur on his graph. That's a big advantage. Expressed in terms of the brightness and of $\alpha$ and $\beta$, that sample I showed you would have the following values: brightness = 21.5%, $\alpha = -0.017$, and $\beta = +0.002$.

**L:** But I *still* can't visualize the chromaticity from those numbers. I'm beginning to think you can't produce a visualizable system and are just stalling around.

**R:** Oh, I forgot to tell you that when $\alpha$ and $\beta$ are zero, the color is a neutral gray.

**L:** *That's* a good scheme. Let's have that in any system we use. But is the color sky blue or is it coral pink?

**R:** We-e-ll now, I think it will be a little clearer when I show you this Fig. 1. There you see that the positive direction of the $\alpha$-axis corresponds to a purplish red; that in the first quadrant we have red and orange and yellow; that the positive direction of the $\beta$-axis corresponds to a greenish yellow; that the second quadrant is yellow-green to green; that the negative direction of the $\alpha$-axis corresponds to a bluish green; that the third quadrant contains blue-green and blue; that the negative direction of the $\beta$-axis corresponds to a blue-violet; and that the fourth quadrant contains violet and purple. You should remember, too, that the nearer you get to the zero point, the more neutral becomes the color—the less pure, that is to say.

**L:** I suppose I could memorize all that in time and be able to visualize those colors, but why all those bluish greens and purplish reds? Can't we change Mr. Hunter's axes around so that they correspond to simple colors? In our product, we often meet certain blues and yellows; can't those two colors, at least, lie on the chromaticity axes?

**R:** I've been considering that very problem, and I have two chromaticity numbers which I call $y$ and $g$, defined by equations:

$$y = \frac{A - B}{A + G + B} \times 100$$

$$g = \frac{-2A + 2.5G - 0.5B}{A + G + B} \times 100$$

where, again,

$A$ is the reading with the amber filter of the reflectometer.
$G$ is the reading with the green filter.
$B$ is the reading with the blue filter.

When we plot those yellows and blues you mention on a $y$, $g$ plot, the yellows fall on the positive $y$-axis and the blues on the negative $y$-axis. Speaking in terms of wave lengths, the positive $y$-axis corresponds to a yellow spectral wave length of 578 m$\mu$ and the negative $y$-axis to a blue spectral wave length of 477 m$\mu$ (Fig. 2).

**L:** Fine. Let's call that axis the *yellowness* axis. Let's refer to negative yellowness as *blueness* to visualize the colors involved. But what's your other axis? Looks like a strange equation to me.

**R:** Colors on the positive $g$-axis are green, corresponding to the spectral light of wave length of 520 m$\mu$; colors on the negative $g$-axis are purple.

**L:** Well, let's call that the *greenness* axis and speak of negative greenness as *purpleness* to visualize the color. This seems to be working out pretty well; but wait, what about my favorite color red?

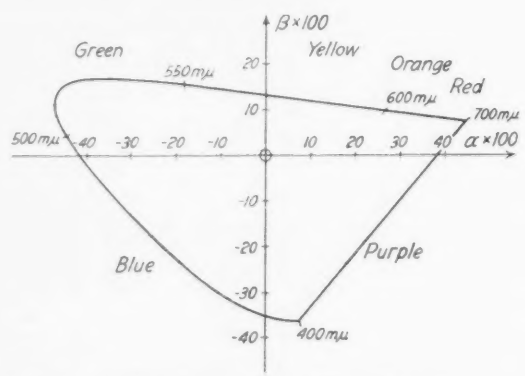


FIG. 1.—Hunter's alpha-beta chromaticity diagram showing locus of spectrum colors.

**R:** Redness, I'm afraid, is the fifth column in this system. We can't have a fifth axis (fortunately), but we can say that red colors lie near a line drawn at 45 degrees between the yellowness and purpleness axis. We can be specific and say that if a color near this line has a numerical value of $y/g = -1 \pm 0.3$ (approximately), the color at hand is red.

**L:** Haven't you a diagram that shows the position of some typical strong colors on a yellowness-greenness chromaticity plot?

**R:** Yes. Figure 2 shows the location of certain selected strong Munsell colors on this *y*, *g* chromaticity diagram. The position of intermediate interpolation colors is also indicated. You will note that the maximum *y*, *g* chromaticity values of these strong colors correspond approximately to 50 of our units.

**L:** I guess I can keep that in mind with a little practice, but tell me, young man, haven't you taken considerable liberty with Mr. Hunter's idea of uniform chromaticity-scales? I see that you use $A + G + B$ in the denominator of your equations where Mr. Hunter used $A + 2G + B$. Aren't you sacrificing that uniform chromaticity-scale advantage which you acclaimed in Mr. Hunter's system?

**R:** Frankly, I used $A + G + B$ for the sake of simplicity and, furthermore, when this work was begun we had not yet received Mr. Hunter's communication of his latest *alpha*, *beta* system.

I can summarize our situation by saying that we *have* distorted Mr. Hunter's chromaticity plane, but to a small enough extent so that for our purposes we can still call our system approximately a uniform chromaticity-scale system. A few diagrams will make this clearer.

Figure 3 shows Hunter's *alpha*, *beta* chromaticity axes plotted on our *y*, *g* diagram. The four-sided figures shown are squares in Hunter's system, and you can get an idea of the extent to which we have distorted Hunter's system by observing how far those figures depart from squareness.*

Figure 4 shows the locus of pure spectrum colors plotted in our *y*, *g* system.† You can compare it with the same locus shown in Fig. 1 in Hunter's *alpha*, *beta* system.

To illustrate in a numerical way the *y*, *g* chromaticity values for some typical Munsell surface colors, a plot has been made for the Munsell hue circle of value 5, chroma 6. This was made from values measured with our Hunter reflectometer for colored papers (obtained from the All Color Company of New York City) and it is shown in Fig. 5. Munsell colors of value 5 are visually about halfway in lightness between black and white. Chroma 6 is considered to be about halfway in chromaticity between gray and strong colors of chroma 12.

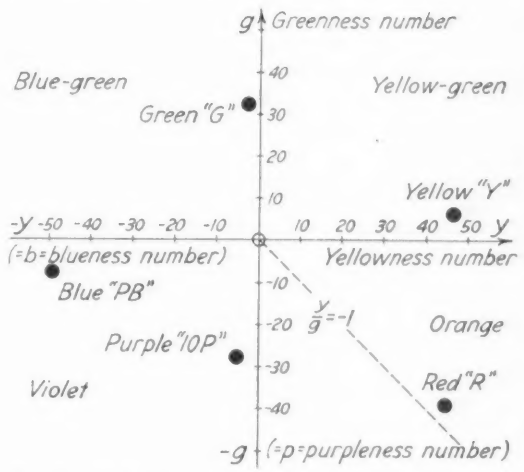


FIG. 2.—Yellowness-greenness chromaticity diagram showing location of typical strong Munsell colors.

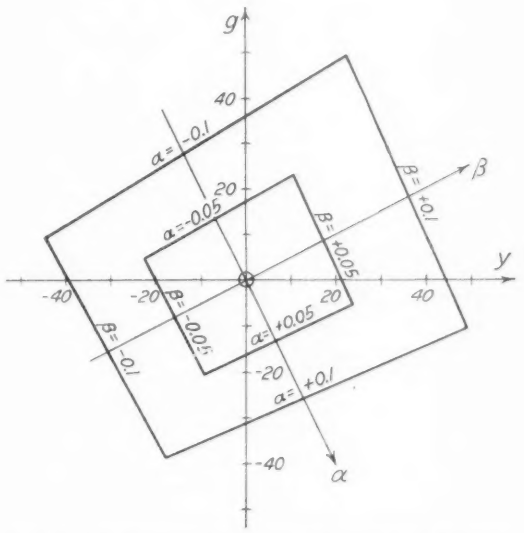


FIG. 3.—Yellowness-greenness chromaticity diagram showing alpha-beta axes and alpha-beta squares.

**L:** All right, unless some one can produce a much better reason for changing than you have indicated, we'll stick to this yellowness-greenness system as defined.

Now, while we're on this subject of uniform chromaticity scales, what about your brightness scale? Is it uniform with respect to visual differences? Let me have a look at a 50% brightness specimen.

**R:** (Hands to **L** a 50% specimen.) Here's our 50% standard gray plate.

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* In the remarks following the presentation of this paper at the Color Symposium, Mr. Hunter stated that he thought we were justified in calling our system a uniform chromaticity-scale system within the limits to which it is possible to state that a system yields uniform chromaticity-scales for large surfaces.

† *y*, *g* values are related to I.C.I. trichromatic coefficients x and y by the following equations, based on relationships supplied by Mr. Hunter:

$$y = \frac{2.16x + 0.98y - 0.98}{0.56x + 0.324y + 0.62} \times 100$$

$$g = \frac{-2.32x + 2.4y - 0.04}{0.56x + 0.324y + 0.62} \times 100$$

**L:** Wow! That looks practically white. Why, if you asked me where that belonged on a scale of black to white, I'd call it about 75% white at least. Can't we do something about this so that a 50% gray surface will look halfway between black and white?

**R:** I think so. If we take the square root of the brightness percentage and multiply it by 10 to restore the scale to a zero to one hundred basis, we get a scale on which that specimen we just looked at would have a value of 70. A 25% brightness specimen would fall at 50 on this new scale.

**L:** Let's call this new scale the *Lightness* scale, and use Lightness numbers instead of brightness percentage from now on.

Now, why don't we arrange our Lightness and our two chromaticity values in a three-dimensional array so that all possible colors will form a "color solid" with dark colors at the bottom and light colors at the top, somewhat as Munsell colors are arranged. We would have a vertical central axis of neutral gray going from black to white, that is, with Lightness numbers from 0 to 100. Extending out from this axis would be horizontal branches representing the yellowness-blueness and the greenness-purpleness axes. Figure 6 shows a model which represents the sort of thing I have in mind.

**R:** That's a good idea, and it is interesting to note that distances between two colors in this space can be assumed as a first approximation to be proportional to the visual difference observed between the two colors. In other words, we can make a first assumption that our three-dimensional array roughly is a "uniform color-scale space."

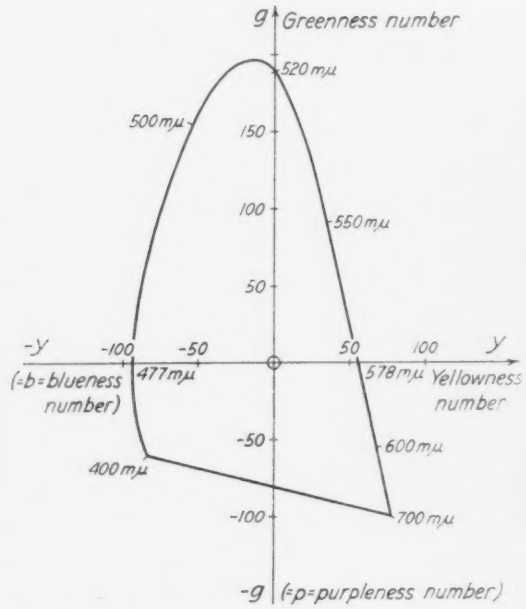


FIG. 4.—Yellowness-greenness chromaticity diagram showing locus of spectrum colors.

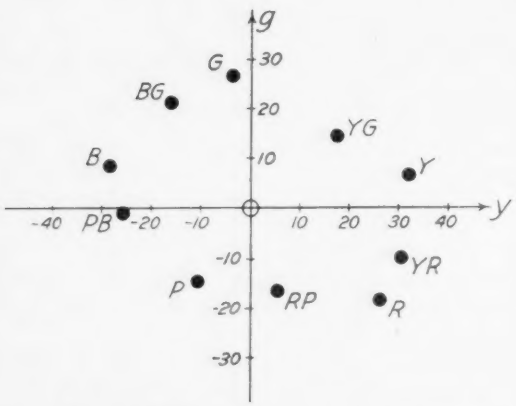


FIG. 5.—Yellowness-greenness chromaticity diagram showing Munsell hue circle of value 5 and chroma 6 (value 5 corresponds to a Lightness number of about 45).

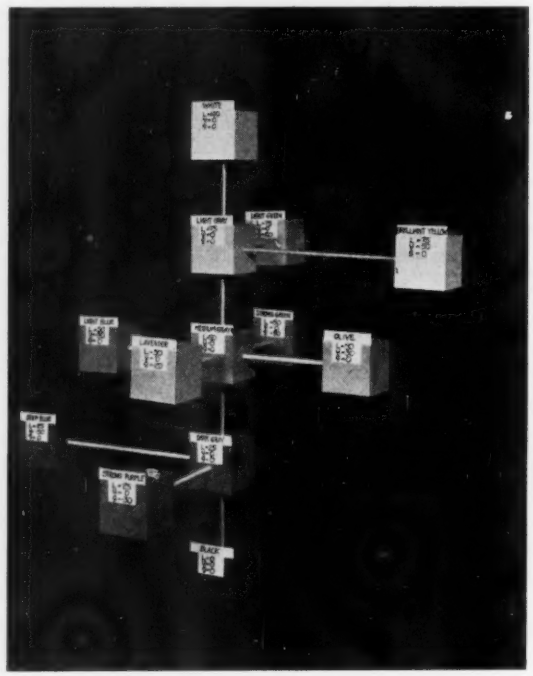

FIG. 6.—"Color solid" in $L$, $y$, $g$ system showing a few typical colors.

**L:** You seem very hesitant about that. Isn't the approximation as good as our approximation to uniform chromaticity scales and to a uniform Lightness scale?

**R:** I'm afraid it isn't, especially at low Lightness levels. The reason is that a given chromaticity difference at a low Lightness level corresponds to a smaller visual difference than the same chromaticity difference at a higher Lightness level, based on the work of Judd, Hunter, and others.

Under our first assumption, however, color differences, $\Delta E$, would be given by

$$(\Delta E)^2 = (\Delta L)^2 + (\Delta y)^2 + (\Delta g)^2$$

which, for many purposes, is sufficiently accurate to be useful. $\Delta L$, $\Delta y$, and $\Delta g$ are, respectively, the differ-

ences in Lightness number, yellowness number, and greenness number for the colors under consideration. This simple equation gives color differences which agree with Dr. Judd's system accurately when the Lightness number is about 25.*

In any case let's call the unit of color difference the "judd," the unit name proposed by I. A. Balinkin of the University of Cincinnati and named after D. B. Judd of the National Bureau of Standards who has been a pioneer in color-difference work.

**L:** Now what about the color data on that specimen you were originally talking about? How does it look in our new system?

**R:** Well, the data become like this,

| | | |
|---|---|---|
| Lightness number | = | 46.4 |
| yellowness number | = | − 1.4 |
| greenness number | = | + 4.9 |

**L:** That's fine. Now I can visualize that color right away. In Lightness, it's nearly halfway between black and white. The chromaticity is down pretty well toward gray, with a greenish hue very slightly toward the bluish side.

Maybe our system will mean something to other people, too. Let's write it up and give them a chance to find out.

## III. Epilogue

The points of importance in connection with the system of surface color measurement just described are summarized as follows:

(1) Measurements are easily made with readily obtainable apparatus that is not too expensive.

(2) Calculations of *Lightness* number, *L; yellowness* number, *y;* and *greenness* number, *g;* are readily made by simple formulas, as follows:

LIGHTNESS NUMBER

$$L = \sqrt{G} \times 100$$

YELLOWNESS NUMBER

$$y = \frac{A - B}{A + G + B} \times 100$$

(Negative yellowness = blueness)

GREENNESS NUMBER

$$g = \frac{-2A + 2.5G - 0.5B}{A + G + B} \times 100$$

(Negative greenness = purpleness)

where *A*, *G*, and *B* are the readings taken with the Hunter multipurpose reflectometer and tristimulus filters amber, green, and blue, respectively.

(3) As a rough approximation, these color numbers are reasonably uniform in their numerical scale with respect to visual judgment of chromaticity differences and Lightness differences. Formulas for estimating the magnitude of color differences have been given.

(4) Because of the choice of axes used, negative yellowness may be called *blueness*, and negative greenness may be called *purpleness* for purposes of color visualization. When yellowness number divided by purpleness number is equal to 1 (with a range from 0.7 to 1.3), the color is red. Other intermediate hues, such as blue-green, violet, yellow-green, etc., are readily visualized from their color numbers, by mentally locating them on the rectangular coordinate chromaticity system which has been shown in Fig. 2.

(5) The yellowness axis corresponds to some of the ceramic yellow colors. Structural blue colors are also located along the negative portion of the yellowness axis.

(6) The maximum chromaticity number of the most brilliant surface colors obtainable is about 50. With respect to Lightness number, the maximum range obtainable is, of course, from 0 to 100. The numerical equivalence of these ranges contributes to convenience and simplicity.

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* Color difference, on the basis of the Judd and Hunter equations, is given more accurately for our color numbers, by means of the equation:

$$(\Delta E)^2 = (\Delta L)^2 + 0.04L[(\Delta y)^2 + (\Delta g)^2],$$

where *L* represents the average Lightness number and the difference terms have their previous significance.

It will be observed that this equation becomes the same as the simpler one given on p. 390, when the Lightness number is 25, because for that value, $0.04L = 1$. At a Lightness number of 50, this equation multiplies *y*, *g* differences by about 1.4 to make them visually equivalent to Lightness differences. At a Lightness number of 80, the corresponding multiplier for *y*, *g* differences is about 1.8.

# V, MEASUREMENT AND DESIGNATION OF SMALL COLOR DIFFERENCES

By Isay A. Balinkin

Abstract

The possibility of establishing object-color tolerances on a firm scientific basis leads to two requirements, namely, (1) the physical measurement of color and its evaluation as a numerical quantity, and (2) the establishment of correlation between color differences expressed physically and the visual perception of such color differences. The development of physical instruments for measuring color and the adoption of standard illuminants, the normal observer, and the standard coordinate system by I.C.I. gave the necessary essentials to satisfy the first requirement. The second requirement is still in the process of development and brief reference is made to several methods proposed for evaluating color differences. The degree of agreement between computed color differences and color differences estimated individually by more than sixty observers on five different colored tile is presented.

The unit of color difference as evaluated from Judd's equation is referred to as a "judd." The range of "small" color differences is assigned a deviation of about fifteen judds from the standard. The problem of establishing an acceptable color tolerance is approached from an experimental standpoint. The selection of colored tile for the construction of "tolerance boards" with maximum color variations of 1, 2, 3, 4, and 5 judds is described. The numerical values for the most desirable and the maximum acceptable color differences are computed from a "color variation ballot." The control of color uniformity in glazed wall tile is discussed. The effect of the variations in glaze thickness and firing temperatures is expressed in terms of a color differential. The latter is shown to depend on the inherent properties of the glaze expressible by partial derivatives and the increments in glaze thickness and temperatures. A graph of variations in reflectances, as measured on Hunter's reflectometer, is shown for a glaze applied in different thicknesses and fired at two different temperatures. A brief reference is made to mathematical functions used to determine the maximum or the minimum value of color variations.

## I. Introduction

The production of goods involves the following three major divisions: (1) specification, (2) manufacture, and (3) inspection. It is proper to consider color in ceramic materials as an essential part of the product, and it requires definite consideration in each of its three production steps.

In an ideal situation, colors would be specified by the art department according to its interpretation of the most pleasing colors or color combinations demanded by the consumers. The manufacturer would reproduce these colors according to these specifications, and the inspection department would simply place its O.K. on the product as it leaves the factory lanes. In such "heaven," the tristimulus color specifications as adopted by the International Commission on Illumination would be all that is necessary.

The actual operating conditions in the ceramic plants unfortunately require not only methods for establishing *color identity*, as it is so well defined by the I.C.I., but also *color differences*. It must be emphasized, however, that it is only when colors can be numerically specified for their identity that a question may be raised in regard to the measurement and designation of color differences. Because the writer for the past six years has had something to do with all three phases of production of ceramic glazed wall tile, problems of color variability will be discussed in relation to that particular industry.

There are several reasons why the ceramic industry can offer an excellent proving ground to determine the usefulness and the applicability of methods recently developed for evaluating color differences, namely, (1) the variety of available colors covers a wide range in hue, lightness, and saturation; (2) the colors are fairly uniform and permanent; (3) the size of the tile ($4^1/_4$ by $4^1/_4$ in.) makes it convenient to measure them on standard instruments; and (4) the color variability from tile to tile is sufficiently large to justify a closer match for tile used in the same installation.

## II. Nature of Problem

The attempt to establish a rational numerical terminology for the specification of color differences must be based, first of all, on the conviction that such a problem is within the realm of physics. It is proper, therefore, to inquire what is meant by a physical concept.[1] The most general criterion for such a judgment can be stated as follows: Physical concepts require that the correspondence between the experience in observation and its description is essentially the same for all observers. It follows from this that no *a priori* decision can be made, whether a problem is a physical or a mental one unless it is subjected first to an experimental test which can reveal the extent of the agreement between several observers.

[1] P. W. Bridgman, The Logic of Modern Physics, p. 6. The Macmillan Co., New York, N. Y., 1927. 228 pp.

The most direct manner for checking the degree of correlation in observations is to evolve a numerical equivalent of their descriptions. A simple example serves to determine whether the concept of length or length difference is within the domain of physics. The procedure would call for two rods of various lengths and an estimation of these lengths by different observers. Judging from daily experience, there would be an essential agreement between different estimates. This accord establishes the physical nature of the concept of length. Elementary as such description may appear, the actual conditions under which an experiment is to be carried out must be carefully specified. It is quite possible to set up such experimental conditions that the descriptions by different observers may not be so consistent as they should be. If, for example, the positions of two rods relative to an observer are not the same, the rod farther away, although actually larger, may appear to be smaller to an observer from whom it is farther away. For more precise estimations, the effect of temperature, stresses, or humidity may again change the observable differences in length.

A similar situation exists when color differences are compared. It is necessary, therefore, to specify carefully all of the factors that actually affect the appearance of color differences before a conclusive experimental check can be carried out.

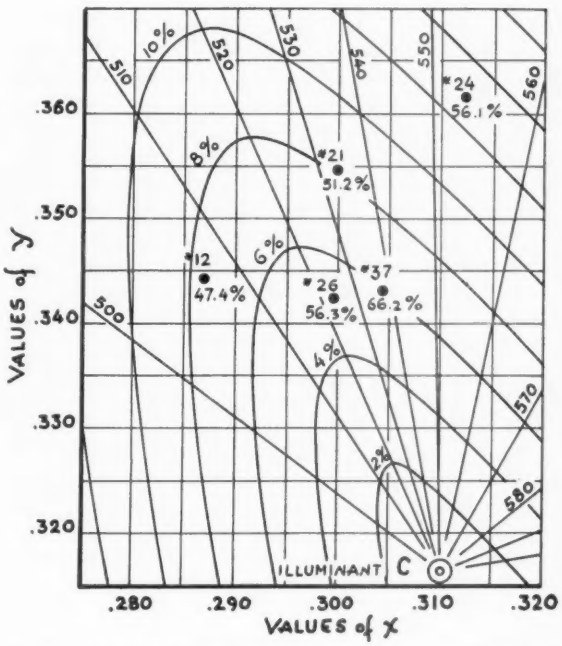


FIG. 1.—I.C.I. chromaticity plane showing positions of five green tile for illuminant C.

## III. Conditions Affecting Visual Estimation of Color Differences

Some of these conditions are already designated in the I.C.I. color specifications, such as the illuminant and standard observer. Five factors will be discussed that may change to a marked degree the magnitude of apparent color differences, in spite of the fact that the I.C.I. specifications of the two colors remain the same.

### (1) Size of Viewing Field

The size of the viewing field plays a doubly important role (1) because, for visual angles somewhere between 3 to 12 degrees, the image is formed within the area of macular pigmentation of the retina, and (2) because, with the increase in visual angle, the perception of color difference is also increased. When two small samples, about one-inch square, are cut from large sheets that differ in color, the visual appearance of color difference may be several times smaller for small samples. The visual mechanism apparently has the property to integrate color differences throughout the extent of the retinal coverage.

### (2) Line of Demarcation

The line of demarcation between two colored samples also plays an important role either in diminishing or enhancing the magnitude of color difference. For color samples that differ chiefly in the lightness attribute, there should be a slight color difference when they are separated by a wide area of some other color. In the absence of a visible line of demarcation, however, the apparent color difference for the same pair may be increased by a factor of 10 or more. Peculiarly enough, no such effect is observable when the two samples differ in hue or saturation or in both.

### (3) Intensity of Illumination

The intensity of illumination, of course, does not change the I.C.I. color specification, but it has the effect to make color differences appear greater as the light intensity is increased, at least up to about 300 foot-candles.

### (4) Color of Background

The color of the background, especially when each sample has a different background color, affects color-difference estimations. For maximum perceptibility of small color differences, the color of the background should be similar to the colors under comparison. A neutral gray of approximately the same lightness as the compared samples is considered to be satisfactory

### (5) Color Uniformity of Samples

When a sample tile varies gradually in color, for example, from the left side to the darker color on the right side, such variation, if not too large, may not be noticeable. Let this tile be broken into two halves along a line between the two sides which show a variation in lightness. If the two halves are now transposed so that the broken edge of the right half is on the left side and the broken edge of the left half is on the right side, there is an appreciable difference in color between the two regions along the broken edges, which orginally were in the middle of the sample. The lighter half of the tile appears to have a lighter edge-region and a darker half a darker edge-region in spite of the fact that physically, both regions have practically the same

color.* Two apparently uniform color surfaces may sometimes show no color difference, or they may be noticeably different, depending on which two particular sides are brought in close proximity.

In carrying out the experiments on the visual estimation of color difference, each of these five factors was predetermined by the actual conditions of the use of tile in service. All tile were carefully chosen for their color uniformity. The viewing field corresponded to a distance of observation at 18 in. The line of demarcation was formed as the tile were placed in contact with each other. Daylight intensity of illumination was approximately 100 to 200 foot-candles. The background was neutral gray with approximately the same reflectance as the sample compared.

## IV. Visual Estimation of Color Differences

To answer the question relating to the physical nature of the color-difference concept, the following experimental procedure was followed. The reflectance curves for thirty-eight green tile, selected at random, were made on Hardy's recording spectrophotometer. Trichromatic coefficients were computed from these curves for illuminant C, and each color was plotted on the I.C.I. chromaticity plane. Every color was designated by a consecutive number from 1 to 38, according to their increasing lightness. Five different colors (Nos. 12, 21, 24, 26, and 37) were then selected to give a fairly wide range of variation in hue, lightness, and saturation. Figure 1 is a chromaticity diagram showing the location of these colors as well as the percentage of luminous apparent reflectance for each color. Table I gives a set of complete data for each one of these five colors.

TABLE I

I.C.I. SPECIFICATIONS FOR GREEN COLORS COMPUTED BY THE 10 mμ METHOD FOR ILLUMINANT C

| Color No. | Trichromatic coefficients x | y | z | Luminous apparent reflectance A (%) | Dominant wave length λ(mμ) | Saturation P (%) |
|---|---|---|---|---|---|---|
| 12 | 0.2870 | 0.3443 | 0.3688 | 47.39 | 506.8 | 7.6 |
| 21 | 0.2999 | 0.3546 | 0.3454 | 51.17 | 533.4 | 8.1 |
| 24 | 0.3122 | 0.3615 | 0.3263 | 56.14 | 553.6 | 12.9 |
| 26 | 0.2995 | 0.3422 | 0.3583 | 56.34 | 523.6 | 5.1 |
| 37 | 0.3044 | 0.3431 | 0.3525 | 66.24 | 538.0 | 6.0 |

### (1) The Ratio Method

The color difference between tile No. 37 and No. 26, which appears to be smaller than for any other pair, was given a value of one unit of color difference. The problem now is to find out whether it is possible to assign a number to the magnitude of color difference between any other two tile in relation to the color difference between the chosen pair of colors designated as a unit. The question proposed is as follows: If the color difference between Nos. 37 and 26 is one unit, how many units of color difference are there, for example, between Nos. 24 and 12? It is the task of estimating directly the ratio of color difference between Nos. 24 and 12 in relation to the color difference between Nos. 37 and 26. In equation (1), $E$ stands for color, and the subscript number indicates the reference number of any one of the colors compared.

$$\frac{E_{24} - E_{12}}{E_{37} - E_{26}} = E_{24} - E_{12} = R_{37-12}. \qquad (1)$$

Because $E_{37} - E_{26} = 1$, $R_{37-12}$, therefore, represents a numerical ratio of color-difference estimation. Such a process of color-difference estimation is called the ratio method.[2] With five different colors, the total number of possible comparisons is ten, and because one pair is already assigned one unit of color difference, only nine additional pairs have to be estimated.

In carrying out the test, an observer was supplied with the five tile, each properly marked at one corner with its number. The following form card was used on which the observer recorded his estimations:

If the total color difference between 37 and 26 is taken to be equal to 1, what number would represent, according to your estimation, the total color difference between

| | | |
|---|---|---|
| 37 − 26 (1) | 26 − 21 ( ) | 24 − 21 ( ) |
| 37 − 12 ( ) | 37 − 24 ( ) | 24 − 12 ( ) |
| 26 − 12 ( ) | 26 − 24 ( ) | 21 − 12 ( ) |
| 37 − 21 ( ) | | |

The results in this test in which sixty observers took part are shown in Fig. 2. The distribution of color-difference estimates is sufficiently consistent to draw

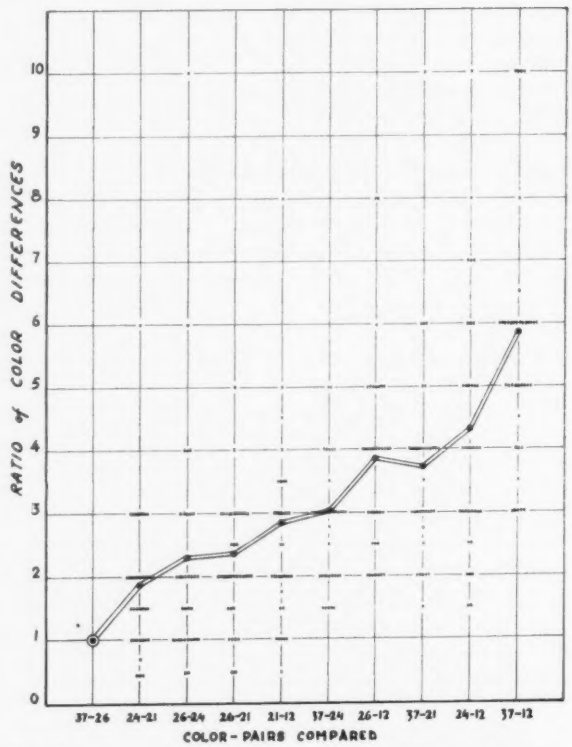


FIG. 2.—Numerical estimations of color differences by the ratio method on five green tile by sixty observers.

* This observation was called to the writer's attention by Arno Illing, in charge of the control work at the Cambridge Tile Manufacturing Co.

[2] S. M. Newhall, "Ratio Method in Review of Munsell Colors," *Amer. Jour. Psychology*, **52** [3] 394–405 (1939).

an average line through solid circles. In spite of the fact that only half of the observers had some previous experience in visual color comparison, there is a significant agreement among most of them as to the rank of color-difference magnitude. The results of this test on the whole are considered to be a sufficient proof of the physical aspect of the problem and also a demonstration that a visual conception of color difference may be expressed numerically.

## V. Evaluation of Color Differences from Physical Measurements

The problem now is to find a mathematical function that will express color differences from direct physical measurements on colors. The success of any method will be judged by its degree of agreement with the average visual evaluation of such color differences as those recorded in Fig. 2.

This problem resolves itself into two parts, namely, (1) a numerical specification of colors based on physical measurements giving three psychophysical parameters for each color and (2) a mathematical equation by means of which the six parameters necessary to specify two colors could be reduced to a single number. To be of practical value, these measurements must be accurate, reproducible, simple, and rapid.

Data secured by the use of the Hardy recording spectrophotometer and the Hunter multipurpose reflectometer will be used for psychophysical color specifications. In evaluating color differences, the following methods will be described and the results tested: (1) Nickerson's index of fading, (2) Nickerson's new formula, (3) Judd's equation, and (4) Adams' equation.

### (1) Nickerson's Index of Fading

A simple method of evaluating color differences was proposed by Nickerson,[3] based on the Munsell notation of colors in terms of hue, value (lightness), and chroma (saturation). The total variation in color between two samples is expressed as a sum of their differences in hue, value, and chroma. To place the differences in these attributes on the same visual perception of color differences, 1 step in value is assumed to be equivalent to 2 steps in chroma and 3 steps in hue (out of 100 at 5 value). The sum is designated as the "Index of Fading" and its numerical evaluation is made by the use of the following formula:

$$I = C/5\,2\Delta H + 6\Delta V + 3\Delta C. \qquad (2)$$

$H$ = hue (expressed in 100 steps along hue circle).
$V$ = value.
$C$ = chroma in Munsell notations.

To evaluate the Index of Fading, each color must first be expressed in Munsell notations. Using the trichromatic coefficients and the charts prepared by Nickerson, based on the Glenn-Killian[4] data, it is a simple matter to convert the I.C.I. specifications into the necessary notations of hue, value, and chroma. The Index of Fading was computed for each of the ten color-pairs, and the ratio of color difference was taken to that of a standard pair. These values, which are represented in Fig. 3 as dots connected by broken lines, may be compared with those obtained by direct visual estimation, which are shown by a double line.

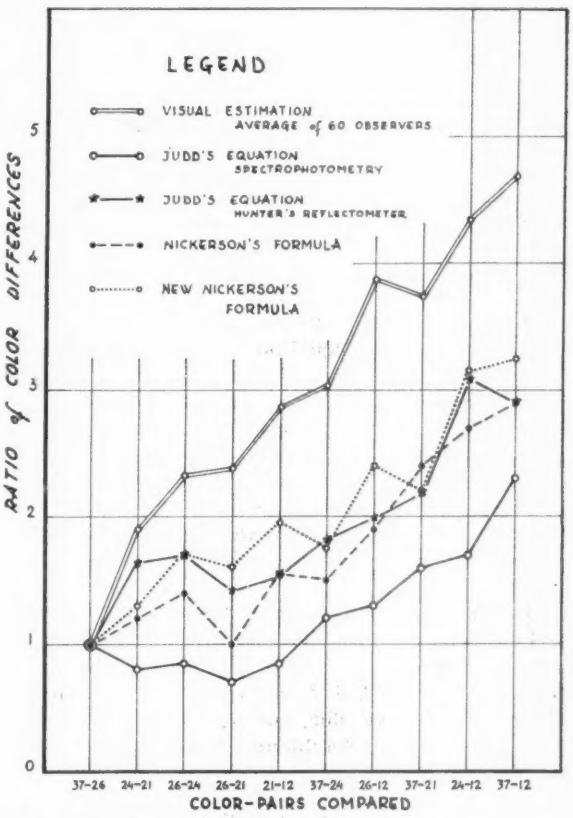


FIG. 3.—Comparison of color-difference ratios by Nickerson's formula, Judd's equation, and averages of sixty observers.

### (2) Nickerson's New Formula

It is possible to modify the expression for Index of Fading to give it the property of a metric in a Euclidean space, namely,

$$I = [(C/5\,2\Delta H)^2 + (6\Delta V)^2 + (20/\pi\ \Delta C)^2]^{1/2}. \qquad (3)$$

New ratios computed from formula (3) are also plotted in Fig. 3 as circles connected by dotted lines, and they show a considerable improvement over the values given by the original Nickerson formula. It is conceivable that a still better agreement may be attained by a further modification of the relative weights assigned to differences in hue, value, and chroma, a possibility that Nickerson suggests in her papers.[3]

In spite of the fact that Nickerson's formula gives results too small by a factor of about 2, the rank order of the color differences is almost in perfect agreement with visual estimations.

[3] (*a*) Dorothy Nickerson, "How Can Results of Fading Tests Be Expressed," A.S.T.M. Standards on Textile Materials, Subcommittee A-7, Committee D-13, October, 1935; (*b*) "Specification of Color Tolerances," *Textile Research*, **6** [12] 505–14 (1936).

[4] J. J. Glenn and J. T. Killian, "Trichromatic Analysis of the Munsell Book of Color," *Jour. Optical Soc. Amer.*, **30** [12] 609–16 (1940); *Ceram. Abs.*, **20** [3] 62 (1941).

TABLE II

SAMPLE CALCULATION OF COLOR DIFFERENCES BETWEEN TILE NOS. 37 AND 26

Evaluation of color differences: $\Delta E = 730\ [G^{1/2}\ (\overline{2\ \Delta a}^2 + \overline{\Delta\beta}^2 + \overline{(\Delta G)/300G)}^2]^{1/2}$

| 1 | 2 Reflectance | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tile No. | Blue | Amber | Green | $A-G$ $\times 10^2$ | $G-B$ $\times 10^2$ | $3B+2A$ $+5G$ | $\alpha$ column 4/6 | $\beta$ column 5/6 | $G$ (avg.) | $\Delta G$ $\times 10^2$ | $\Delta L$ | $\Delta$ | $\Delta E$ judd |
| 26 | 0.460 | 0.446 | 0.514 | −6.8 | 5.4 | 4.842 | −1.404 | 1.115 | 0.561 | 9.4 | 5.36 | 2.24 | 5.81 |
| 37 | 0.535 | 0.537 | 0.608 | −7.1 | 7.3 | 5.719 | −1.241 | 1.296 | | | | | |

## (3) Judd's Equation

Another method of computing color differences was developed by Judd,[5] based on the use of Maxwell's triangle yielding a uniform chromaticity scale. Equation (4) gives a mathematical function for evaluating color differences, $\Delta E$ in terms of the trilinear coordinates, $r$, $g$, and $b$, derived from I.C.I. trichromatic coefficients and from apparent reflectances, $A$.

$$\Delta E = 600\ [A^{1/2}\ (\overline{\Delta r}^2 + \overline{\Delta g}^2 + \overline{\Delta b}^2) + 0.005\ \overline{\Delta A}^2/A]^{1/2} \quad (4)$$

The magnitude of the multiplying factor of 600 was so chosen that the equation, $\Delta E = 1$, represents a surface-color difference of some significance in industrial or commercial practice. This unit of color difference is about five times larger than the least perceptible difference under good observation conditions.

With the aid of equation (4) and of the I.C.I. specifications for five green colors, $\Delta E$ was evaluated, and the ratios of color differences were computed. These are shown graphically in Fig. 3 as circles connected by solid lines.

Judd's equation can be made the basis for computing color differences from three readings obtained on Hunter's multipurpose reflectometer.[6] In terms of the apparent reflectances, $B$, $A$, and $G$, of light bands passing through respective blue, amber, and green filters, the expression for the color difference, $\Delta E$, is given by equation (5).

$$\Delta E = 730\ [G^{1/2}\ (\overline{2\Delta\alpha}^2 + \overline{\Delta\beta}^2 + \Delta G/300G]^{1/2}. \quad (5)$$

$$\text{Where } \alpha = \frac{A-G}{3B+2A+5G}.$$

$$\beta = \frac{G-B}{3B+2A+5G}.$$

The green filter in the reflectometer was so selected that, in combination with the spectral sensitivity of the photoelectric cell, the apparent reflectance, $G$, is almost identical with the luminous apparent reflectance, $A$, used in equation (4). The constants in equation (5) were properly chosen to give nearly the same numerical magnitude for a unit of color difference as in the original Judd equation.

For the purpose of comparison, all of the values of color differences were reduced to the arbitrary chosen unit of color differences between 37 and 26, which came out to be equal to 5.81 units. The actual steps necessary to make a calculation of color difference between two such samples are given in Table II. Laborious as these calculations appear at first sight, they can be greatly simplified by the use of a graphical method. It was previously suggested to give this unit of color difference the name, "judd."[7] The everyday practice of visualizing and actually using a definite unit to express color difference was found to be of great help in the control of color uniformity. In recommending a wider use for such a unit and its name, it is felt that it not only honors the man who was primarily responsible for developing the basic principles on which color-difference measurements may be performed, but it also has a psychological value among those whose responsibility it is to maintain an established color tolerance within a specified number of "judds."

[5] D. B. Judd, "Specification of Uniform Color Tolerances for Textiles," *Textile Research*, **9** [7–8] 253–308 (1939).

[6] R. S. Hunter, "A Multipurpose Photoelectric Reflectometer," *Jour. Research Nat. Bur. Stand.*, **25** [5] 581–618 (1940); R.P. 1345; *Ceram. Abs.*, **20** [7] 175 (1941).

[7] I. A. Balinkin, "Industrial Color Tolerances," *Amer. Jour. Psychology*, **52** [3] 428–48 (1939).

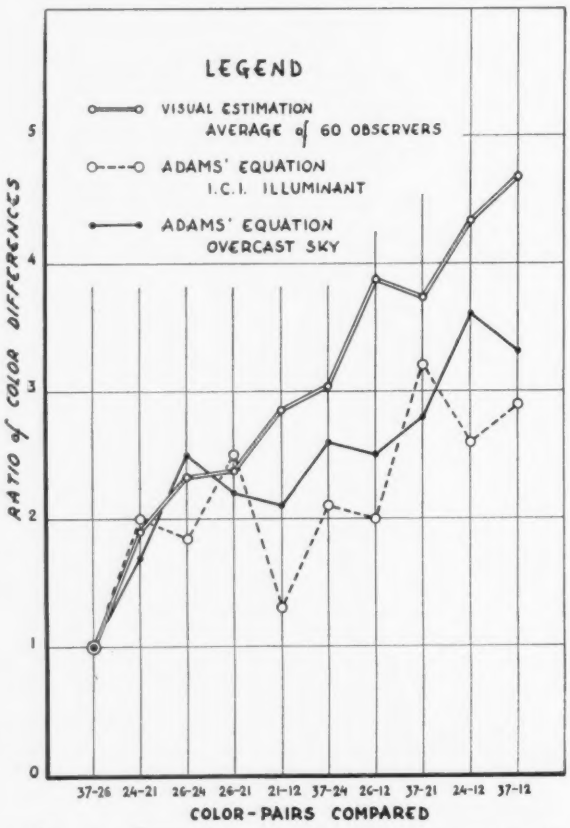


FIG. 4.—Comparison of color-difference ratios by Adams' equation for I.C.I. illuminant C and by the Taylor and Kerr energy distribution for overcast sky.

### (4) Adams' Equation*

The most recent addition to the methods of computing color differences in terms of visual perception is due to Adams.[8] For the standard illuminant C, the tristimulus values $X$, $Y$, and $Z$ are first converted into sensation values of $V_x$, $V_y$, and $V_z$ by using the Munsell, Sloan, and Godlove[9] value (lightness) function. The total difference in color of a pair of samples is then computed from equation (6) as follows:

$$\Delta E = \{\Delta V_y^2 + [7.5\ \Delta(V_x - V_y)]^2 + [3.0\ \Delta(V_z - V_y)]^2\}^{1/2}. \quad (6)$$

These values are represented graphically in Fig. 4. Adams also computed the values for relative color differences using the Taylor and Kerr[10] energy distribution for overcast sky instead of illuminant C (see Fig. 4). A still closer agreement of Adams is shown by reducing the ratios to a geometric mean rather than by expressing all results in terms of the smallest difference between 37 and 26.

There is a significant variance in the values of color ratios for the I.C.I. illuminant C and the overcast sky. It would be interesting to see the color ratios computed by the Nickerson formula and the Judd equation, based on energy-distribution data given by Taylor and Kerr,[10] and to determine the ratios, if, instead of daylight, an illuminant C were used during the test on visual evaluation of color differences on five green tile. The question of whether the I.C.I. illuminant C is a sufficiently true representation of an "average daylight" for color-match work should receive a further inquiry.

It is too early to draw the final decision as to the best method of computing color differences. Whereas the numerical values of Adams in many instances are in better accord with visual estimations, the rank of color differences is inferior. Further studies in this field are in progress, and there is no doubt that, in due time, the numerical values of color differences computed from psychophysical data will be in complete accord with the direct visual perception of such color differences.

The data secured on sixty observers cover a range of color differences equal to about 35 judds, which is probably the extreme limit of what one may call "small" color differences. Half of that amount would certainly be a more valid range. The methods of Judd and Nickerson were never intended for too wide a range. The fact that the rank of color differences came out substantially in agreement with the experimental data is of sufficient significance to justify the attempts at practical applications in the field of "color engineering."

If further trials are to be conducted by the use of the ratio method, the advisability of reducing the range of color variation to about 15 judds should be considered because, as will be shown later, problems in color-difference evaluation are of the greatest importance within that range.

## VI. Types of Color Space

The fact that any color may be completely specified by its three parameters suggests a possibility of representing any given color by a point in space, whose three coordinates uniquely specify the numerical magnitudes of the three color attributes. Colors, therefore, may be considered to correspond to a manifold of points in a selected group of three coordinates. Interpreted geometrically, such manifold constitutes a color space, where, for each point in space, there is an equivalent color.

In a color system established by Munsell, the color space is defined in a cylindrical coordinate system of hue, lightness (value), and saturation (chroma). The concept of color space is useful in visualizing the spatial arrangement of colors.

The geometrical properties of a space may be related to the visual perception of color differences if such color perceptions are related to the distance of separation between points representing colors.

From the standpoint of evaluation of small color differences, the most useful color space is one that would satisfy the following requirement: *The ratio of linear distances between any two pairs of points agrees numerically with the visual estimation of color differences of these two color pairs estimated by the ratio method.* This requirement also implies that equal linear distances correspond to equal sensations of color differences, and a larger linear distance corresponds to a greater perceptible color difference in every part of the color space. A color space possessing this property where the location of colors is based on physical measurements is defined as the homogeneous and isotropic psychophysical color space.[7]

Different methods of evaluating color differences in fact are defining the geometrical relationships between colors, wherein the expression for $\Delta E$ becomes a metric in that particular color space. A practical application of such color space for the purpose of selecting a series of colors is described in section VII.

## VII. Tolerance Boards

One of the consequences of the development in the method of measuring small color differences is the possibility of specification of color tolerances. In practically every instance, color-tolerance specification defines the *maximum acceptable* color difference although in some instances the *most desirable* color difference may be also specified.

A direct method of finding out the proper color tolerance would be to present for the consumer's consideration a number of selected samples in which the range of maximum color variation would vary within predetermined limits. Each exhibit is to be prepared in such a form as to simulate the actual conditions under which

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[7] The author is grateful to E. Q. Adams, who kindly computed color differences for the color-pairs of five green samples used in the tests.

[8] E. Q. Adams, "X–Z Planes in the 1931 I.C.I. System of Colorimetry," *Jour. Optical Soc. Amer.*, **30** [12] 657 (1940).

[9] A. E. O. Munsell, L. L. Sloan, and I. H. Godlove, "Neutral Value Scales: I, Munsell Neutral Value Scale," *Jour. Optical Soc. Amer.*, **23** [11] 394–411 (1933).

[10] A. H. Taylor and G. P. Kerr, "Distribution of Energy in the Visible Spectrum of Daylight," *Jour. Optical Soc. Amer.*, **31** [1] 3–8 (1941).

these variations are seen. The consumers are then asked what color variations they would be willing to accept.

In the field of glazed ceramic wall tile, the variations from a standard are found to be in all three attributes of color. It was decided, therefore, that within each set, colors should vary in hue, lightness, and saturation. The magnitude of color variation within each set of nine tile arranged in the form of a square was selected to be 1, 2, 3, 4, and 5 judds. Such "tolerance boards" were prepared for three different colors.

The nine tile comprising a tolerance board were selected in such a way that there was a progressive color difference between two adjacent tile equal to one eighth of the maximum color difference within each tolerance board; that is, for a tolerance board with a maximum color difference of 4 judds, the nine selected tile showed only $^1/_2$ judd between each pair of consecutive tile. Because of the "Illing effect," previously described, it is possible to arrange the nine tile in such order that the appearance of the board from the standpoint of color variability may be either enhanced or weakened. An arrangement was found after a few trials which gave an average representation of color variations within each tolerance board. This order is shown below, where letters from *A* to *I* stand for different tile.

| | | |
|---|---|---|
| B | C | D |
| I | A | E |
| H | G | F |

The color differences between two adjacent tile following alphabetical order, *A–B*, *B–C*, *C–D*, etc., up to *H–I*, were equal but progressively increasing from tile *A* to *I* as follows:

$$A\text{–}B = B\text{–}C = C\text{–}D = \ldots . H\text{–}I.$$
$$A\text{–}B = (A\text{–}C)/2 = (A\text{–}D)/3 = \ldots . (A\text{–}I)/8. \quad (7)$$

Tile, selected according to these specifications, were mounted on Masonite boards with appropriate notations on the reverse sides.

The selection of nine tile for each tolerance board with a uniform interval of color variation and a limited maximum range at first did not appear to be practicable. It was the development of the geometrical method of representing colors and evaluating color differences which made the solution of this problem feasible.

The procedure was as follows: About 200 tile of a desired color were picked at random from different production runs, and each tile was assigned a number. The color of each tile was measured on Hunter's reflectometer and the chromaticity components, $\alpha$ and $\beta$, were computed. These points, each marked by their respective numbers, were plotted on the $\alpha$, $\beta$ plane. Pins were inserted perpendicularly to the chromaticity plane to represent the reflectance of each tile. The terminal point of each pin is a geometrical position of the color for that tile in the color space of $\alpha$, $\beta$, and $G$. It was surprising to find that within a group of 200 tile there were very few that showed identity in all three color attributes. A "yardstick" for measuring color differences in judds was made in accordance with the average reflectance of the whole group of tile.[7]

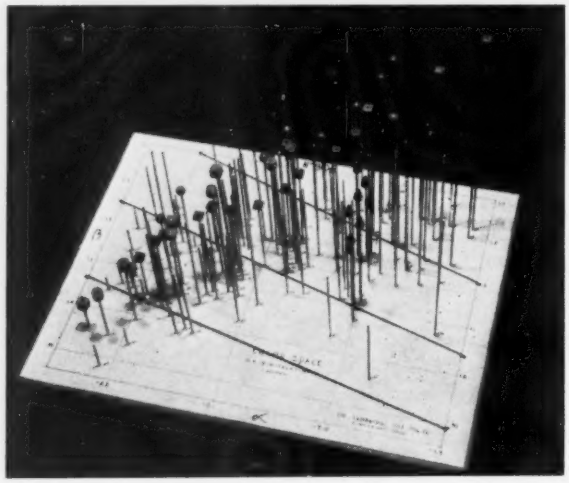

FIG. 5.—A model representing an arrangement of colors by points in a color space of $\alpha$, $\beta$, and $G$. Each group of nine selected tile is shown by differently shaped figures attached to the terminal points; the following shapes designate tile that were selected for different ranges of tolerance boards: cones, 1 judd; pyramids, 2 judds; balls, 3 judds; cylinders, 4 judds; and cubes, 5 judds.

The selection of tile was made by a visual inspection of nine consecutive points, all lying approximately equidistant along a straight line, whose terminal points were numerically equal to the required number of judds as marked on the color difference "yardstick." Figure 5 shows a photograph of the actual model built for selecting tile for one color range.

The availability of tolerance boards offers the manufacturer a direct way of finding out what the consumer wants or will tolerate in the color variation of the product. A set of five tolerance boards, numbered at random, is exhibited under proper illumination to a selected group of people. They are asked to examine each board within a group of three color ranges and then cast a "Color Variation Ballot" which reads as follows:

Granting that the variation in color from tile to tile is one of the distinctive features of the product and assuming that the factory is able to maintain and control the variation as shown on the board,

(1) Which board in your opinion represents the *most desirable* color variation?

| 74 | 80 | 82 |
|---|---|---|
| Dusty pink | Robin's egg | Café au lait |
| Board No. ( ) | ( ) | ( ) |

(2) Which board in your opinion represents the *maximum possible* color variation which would be acceptable to you as a consumer?

Board No. ( ) ( ) ( )

The results of voting by forty-six observers are given in Table III. The average tolerances, $T_d$, most desirable, or $T_a$, maximum acceptable, were computed by the following formula:

$$T = \left(\sum_{k=1}^{5} K \cdot V_k\right) \Big/ \left(\sum_{k=1}^{5} V_k\right). \qquad (8)$$

Where $V_k$ = number of votes cast for a tolerance board having a color difference of $K$ judds to be either most desirable or maximum acceptable.

TABLE III

COLOR TOLERANCES IN JUDDS

| Glaze No. | 74 | 80 | 82 |
|---|---|---|---|
| Most desirable ($T_d$) | 1.3 | 2.2 | 1.9 |
| Max. acceptable ($T_a$) | 2.4 | 2.8 | 2.8 |

These results indicate that there is a good consistency in correlating visual estimations of color differences with the numerical evaluation of these differences by the Judd equation. There seems to be an indication, however, that color differences in the range of red corresponding to glaze No. 74 are too small when they are computed from the Judd equation.

## VIII. Numerical Values of Color Tolerances

The procedure outlined allows the manufacturer to obtain valuable information regarding either desirable or maximum permissible color variations. It is of interest to record a spread of approximately one judd between most desirable and maximum acceptable color variations for ceramic wall tile. This fairly narrow limit of color variability may appear to be more severe than the actual use of the product requires, yet such was the response of the observers. As pointed out by Judd,[11]

> The manufacturer would be only too glad to use larger tolerances, but the purchaser in many cases either does not understand the necessary connection between size and color tolerance and cost per accepted unit or else he uses the color tolerance as a loophole through which to escape an unfavorable contract when there is no other way to escape it.

If the size of color tolerance could be definitely specified and accepted, it would serve well to guard the interests of the manufacturer and also of the consumer. It is one of the problems in which the Inter-Society Color Council is taking an active part.

With the gradual progress in the methods and instrumentation for evaluation of color differences, color tolerances in numerical terms will replace the present wordy and often ambiguous terminology. In April, 1940, the I.S.C.C. Committee on Standardization of Discriminative Terms in Color tentatively adopted a numerical scale to designate the terminology used for small color differences in the dye industry:

| | Judds |
|---|---|
| Trace | 0.0– 0.5 |
| Slight | 0.5– 1.5 |
| Noticeable | 1.5– 3.0 |
| Appreciable | 3.0– 6.0 |
| Much | 6.0–12.0 |
| Very much | More than 12 |

In the ceramic industry, where the composition and control of the fired materials cannot possibly be held within the same degree of accuracy as in the dye industry, the numerical magnitudes of color differences should be at least doubled for the same word terminology.

The numerical magnitude of color tolerance must depend on the specific usage or utility of the goods where color differences serve as indicators of variations in certain desired properties. It is, therefore, futile to expect that a single color tolerance could ever be established.

### (1) Specification

In most ceramic plants, the existing color pallet for wall and floor tile is a heritage of the past, based on market preferences, ceramic color technology, and a necessity to match colors to bathroom and kitchen accessories. The modern trend of greater emphasis on color and the increasing consciousness of buyers of the pleasure to be derived from pleasing color combinations demands an increase in the number of manufactured colors. The limitations that have been cited unfortunately restrict the possibility of a unified color system which would offer a limited number of colors to produce the maximum number of most pleasing combinations of color harmony. The coordinate efforts of art and sales promotion departments in a ceramic plant are constantly calling on the development department to duplicate a certain color, usually specified by a material standard. A ceramic engineer can rarely score a three-dimensional "bull's eye" in the color space. A numerical value of color tolerance within a radius of approximately 12 judds from a given color standard should be considered in most instances to be a satisfactory match for a newly developed glaze.

### (2) Consumers' Acceptance

The tolerance among tile for a single installation, as reported in section VIII (1), is desired to be within 3 judds. This rather stringent demand makes it necessary to rely on the shading department to group the tile of any particular glaze into more than one shade. The term "shade" may be defined as a group of colors within arbitrary limits of variations in hue, lightness, and saturation. Numerically, 3 judds may be considered (provisionally) to define "shade."

When a customer selects a color for wall tile, the numerical color tolerance in regard to the actual color finally supplied should be extended to about 9 judds. All ceramic plants state explicitly that color variation in fired-clay products is an inherent property of the materials used, and a departure of 9 judds from the sample should be accepted as a satisfactory match. This would allow the manufacturer to establish three shades

[11] D. B. Judd, "Letter to the Editor," *Bull. Amer. Ceram. Soc.*, **17** [9] 379–81 (1938).

for the same color listed in the catalogue by its glaze number, color name, or material standard.

### (3) Manufacture

In view of the tolerance of the consumer's acceptance, the control of color uniformity in manufacture should be limited to 9 judds as the maximum departure from a chosen standard. In an ideal situation, all factory runs would show not more than 3 judds in color variation. The control of color uniformity will be discussed more fully in section IX.

### (4) Inspection

Numerical tolerances in shading departments are usually set up by the material standards known as "shading boards." The limits of these shading boards are the same as those of consumers' acceptance in a single shade, that is, 3 judds. Three shades are selected from several production runs so that they cover the most frequently occurring departures from the standard color. The tolerance in selecting tile for the shading boards should not be larger than $^1/_4$ judd. It is impossible in this discussion even to touch on the subject of the "mechanism of shading" itself, such as the quality and quantity of illumination, shading board design, matching fields, tests for color vision, and color-discriminating ability of the workers. Unless all of these are carefully planned, well constructed, and properly supervised, no rigid set of numerical color tolerances will save the management from frequent complaints and loss due to rejection by the customer of a shipment that was off color.

## IX. Control of Color Uniformity

The most significant practical application of the methods and instruments developed for measuring small color differences can probably be found in the problem of establishing and maintaining a scientific control of color uniformity. There are usually several factors well known to every ceramist that affect the final color of a glazed ceramic tile. In mass production, these factors depend on certain physical and chemical tolerances which must be set up so that the maximum color variation will not exceed a certain limit. It is obvious, therefore, that a *consistent* color uniformity depends on the tolerances maintained in these physical and chemical factors. The use of the adjective "consistent" is necessary because, in certain instances, it is possible to achieve a uniformity in color if it happens that the variations in any two or more factors are in such a direction that they neutralize each other.

It follows, therefore, that for the production of articles within a certain color tolerance, it is necessary, first, to measure numerically each one of the physical and chemical agents and, second, to determine the effect of variation of these agents on the final color. If more than one agent is involved, a measured variation must be introduced into a single agent and all of the others must be kept constant. It will thus be possible to find out to what extent that single agent is responsible for variation in color. The same procedure should be applied to all possible constituents or manufacturing elements which, in the experience of the control or development engineer are important in determining the final color of a glaze. The results of such tests can supply the information on the maximum permissible variation in physical and chemical agents to produce a color not exceeding a certain color tolerance limit. As an approximation, the maximum color deviation from a standard may be assumed to be given by the sum of maximum color deviations of each one of the independent agents.

In the manufacture of glazed ceramic tile, for example, the effect of only two factors on the color of a final product will be considered, namely, (1) the thickness, $a$, of a fired glaze and (2) the temperature, $t$, at which it was fired. If $\Delta E$ represents a color difference between a standard and a sample tile because of the difference of thickness of the two glazes and temperatures at which they were fired, then

$$\Delta E = \Delta a \left(\frac{\partial E}{\partial a}\right)_t + \Delta t \left(\frac{\partial E}{\partial t}\right)_a. \qquad (9)$$

$(\partial E/\partial a)_t$ = partial derivative of color, $E$, as to glaze thickness at constant temp., $t$.
$(\partial E/\partial t)_a$ = partial derivative of color as to temp. of firing at standard glaze thickness, $a$.
$\Delta a$ and $\Delta t$ = measured differences in thickness and temperature in range of standard specifications.

It is important to observe from equation (9) that, to secure the minimum value of $\Delta E$, the factors under the manufacturing control are determined entirely by $\Delta a$ and $\Delta t$ because $\partial E/\partial a$ and $\partial E/\partial t$ are the intrinsic properties of the glaze itself. It may be stated in general, therefore, that the color variation in a glaze depends on two groups of factors: In group (1) are found the chemical or inherent properties of the glaze expressed by partial derivatives; and in group (2) are the physical or manufacturing deviations from the standards expressed by the differences in $a$ and $t$. An ideal case, wherein $\Delta E = 0$ may be achieved by the use of a glaze having $\partial E/\partial a = 0$ and $\partial E/\partial t = 0$, as shown in equation (10).

$$\Delta E = \Delta a \cdot 0 + \Delta t \cdot 0 = 0, \qquad (10)$$

no matter how large $\Delta a$ and $\Delta t$ may be; similarly, $\Delta E = 0$, when $\Delta a = 0$ and $\Delta t = 0$, that is,

$$\Delta E = 0 \cdot \partial E/\partial a + 0 \cdot \partial E/\partial t = 0, \qquad (11)$$

no matter how large $\partial E/\partial a$ and $\partial E/\partial t$ may be. A combination of $\partial E/\partial a = 0$ with $\Delta t = 0$ or $\partial E/\partial t = 0$ and $\Delta a = 0$, furthermore, will make $\Delta E = 0$.

Under usual manufacturing conditions, none of the zero equalities can be expected because the color of all glazes is affected to a smaller or greater extent by the thickness of glaze application and the temperature of firing. When the numerical values of $\Delta E$, $\partial E/\partial a$, and $\partial E/\partial t$ are known, however, it is possible to compute the tolerances for $\Delta a$ and $\Delta t$. If $\Delta a$ and $\Delta t$ cannot be held within such specified limits, the larger values of $\Delta E$ must be used or the inherent color variability of the glaze under consideration must be changed.

The use of the color-uniformity control equation (9) provides the industry with specific information on

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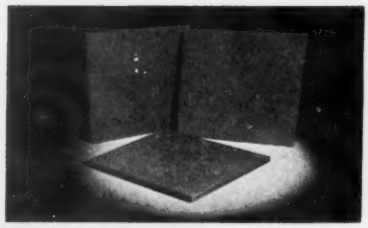

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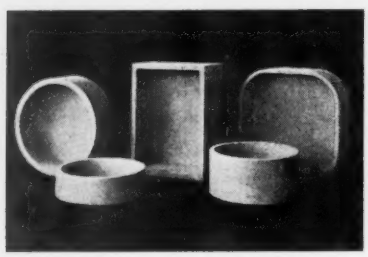

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which to establish a rational control of color uniformity.

The determination of the rates of color variation as a function of thickness or (and) temperature is made by the application of glaze in gradually increasing thicknesses, for example, to two sets of 10 tile each. One set is fired at a low temperature and another at a high temperature, covering the range of temperatures that is known to exist in the kiln. The color of each tile is then carefully measured on Hunter's reflectometer, and the reflectances, $B$, $A$, and $G$, are plotted as shown in Fig. 6. Computations are made from this graph to determine $(\partial E/\partial a)_t$ (judds per mil of glaze thickness) and $(\partial E/\partial t)_a$ (judds per cone temperature difference). With these values at hand, the tolerance limits for $\Delta a$ and $\Delta t$ may be set up so that $\Delta E$ would not exceed a definite amount.

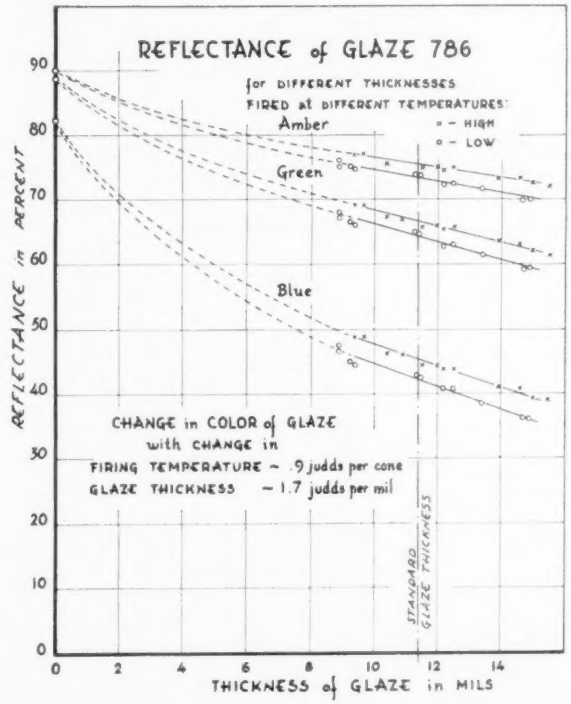


FIG. 6.—Reflectances of tile of various glaze-thicknesses fired at two different temperatures and measured on the Hunter reflectometer.

The numerical values for $\partial E/\partial a$ and $\partial E/\partial t$ are true indicators of the property of the glaze in regard to its color variation, depending on the variations in thickness or temperature. In considering the acceptance of a newly developed glaze, numerical limits may be required for the magnitude of these partial derivatives before the glaze is accepted for production.

It is a frequent occurrence in ceramic as well as in other industrial plants that, when an off-color is encountered, each manufacturing department is liable to place the blame somewhere else. If the glaze thickness is measured and the reflectances are located on the graph of a standard glaze (Fig. 6), the responsibility for the off-shade may be placed on the lack of control either in the glaze preparation, in spraying, or in firing. This in itself is a real help to a more efficient control of color uniformity.

By an inspection of Fig. 6, for a glaze of thickness, $a$, approaching zero, the following partial derivative is observed:

$$(\partial E/\partial a)_{a \to 0} = \text{maximum.}$$

As the thickness of the glaze increases up to $a = s$, the curves approach a region where there is no further decrease in reflectance, that is,

$$(\partial E/\partial a)_{a \to s} = \text{minimum.}$$

In regard to the effects of temperature for a glaze of thickness approaching zero, the partial derivative is

$$(\partial E/\partial t)_{a \to 0} = \text{minimum; however, } (\partial E/\partial t)_{a \to s} = \text{maximum.}$$

A question may be asked, therefore, whether for certain operating conditions such a relationship may exist between the four variable functions for determining $\Delta E$ that its value is either a minimum or a maximum. The mathematical functions answering this question are in the following form:

$$\frac{\partial}{\partial a}\left(\frac{\partial E}{\partial a}\right)\Delta a + \frac{\partial}{\partial a}\left(\frac{\partial E}{\partial t}\right)\Delta t = 0, \text{ and}$$

$$\frac{\partial}{\partial t}\left(\frac{\partial E}{\partial a}\right)\Delta a + \frac{\partial}{\partial t}\left(\frac{\partial E}{\partial t}\right)\Delta t = 0.$$

These functions lead to

$$\frac{\partial^2 E}{\partial a \partial t} = -\frac{\Delta a}{\Delta t}\frac{\partial^2 E}{\partial a^2} = -\frac{\Delta t}{\Delta a}\frac{\partial^2 E}{\partial t^2}.$$

The meaning of these functions unfortunately cannot be discussed at this time.

## X. Conclusions

The results of visual tests indicate that it is possible to establish a numerical scale for visual perception of color differences. A considerable amount of additional data will be required to provide the information for various spectral regions.

Although the agreement between visual estimations of color differences and those computed from physical measurements is not satisfactory, the degree of approximation has proved to be of practical industrial value in the problems of consumers' acceptance and the control of color uniformity. The indications from a recent work of Adams point to the possibility of affecting a better correlation between the physical measurements and the observations.

From the instrumental standpoint, Hunter's reflectometer is found to be the least expensive and quickest way to secure the necessary data for the measurement of small color differences. Its successful use depends a great deal on the care necessary to secure reliable and reproducible results. The reduction of physical measurements to equivalent terms of visual perception is still a tedious and lengthy process requiring at least ten minutes for a pair of samples.

In spite of all of these difficulties, the advantages of numerical specification of color differences rather than "the use of the expression 'color match' without an indication of allowable departure"[12] can benefit every ceramic manufacturing company in its productive efficiency as well as its consumers' relationships.

**Acknowledgment**

The material presented in this paper is the result of the helpful cooperation of many persons. Among them should be mentioned Lyman J. Briggs, K. S. Gibson, R. S. Hunter, and particularly Deane B. Judd of the National Bureau of Standards and Miss Dorothy Nickerson of the U. S. Department of Agriculture. It is a pleasure to acknowledge a sympathetic attitude of R. C. Gowdy, Dean of the Engineering College, and of S. J. M. Allen, Chairman of the Department of Physics, in permitting this research project to be a cooperative enterprise between the University and the industry. Thanks also are due to Boris Podolsky of the Department of Physics for his help in some of the mathematical formulations. Last but not least, the author is happy to express his grateful thanks to Charles H. Burchenal, president, and Henry E. Meyer, vice-president, of the Cambridge Tile Manufacturing Company, without whose generous support and liberal stand this paper would not have been written.

[12] A. C. Hardy, Handbook of Colorimetry. Massachusetts Institute of Technology Press, Cambridge, Mass., 1936. 85 pp.

Department of Physics
University of Cincinnati and
Cambridge Tile Manufacturing Company
Cincinnati, Ohio

# EFFECT OF FURNACE ATMOSPHERE ON COLORS DERIVED FROM CHROMIC OXIDE*

By William L. Peskin

Abstract

Chromic oxide and a feldspathic glaze containing chromic oxide were heated to several different temperatures in a furnace atmosphere that contained varying amounts of oxygen, nitrogen, and carbon dioxide. The colors of the resulting samples were measured with the Hunter multipurpose reflectometer, and the color changes were plotted as a function of these variables.

## I. Introduction

The greater emphasis on ceramic colors has caused research on their industrial control to become increasingly important. The technique of measuring and specifying or describing colors has only recently become the subject of standardization, and it is now possible to give a quantitative representation of the effect of different variables on color.

Two of the most important variables in the production of ceramic colors are temperature and furnace atmosphere. In the present study, samples of chromic oxide pigments were subjected to different temperatures and to varying proportions of oxygen nitrogen and carbon dioxide, and the color changes were measured. Similar experiments were carried out on feldspathic glazes containing chromic oxide.

### (1) Literature on Chromium

The two principal oxides of chromium are the green $Cr_2O_3$ and the red $CrO_3$, which are formed by the evaporation of chromic acid, $H_2CrO_4$. On heating, $CrO_3$ decomposes and ultimately is converted to $Cr_2O_3$. In addition to these two oxides, several nonstoichiometric oxides have been reported in the literature.[1] The most recent work[2] concludes that the decomposition of $CrO_3$ occurs in two nonstoichiometric stages. Two oxides

* Received June 20, 1941.

This research was carried out under the Edward Orton, Jr., Ceramic Foundation Fellowship at the Department of Ceramics, Rutgers University, New Brunswick, N. J.

[1] (*a*) W. C. Ball, "Slow Decomposition of Ammonium Chromate, Dichromate, and Trichromate by Heat," *Jour. Chem. Soc.*, **95** [1] 87–93 (1909).

(*b*) G. N. Ridley, "Chromium Dioxide," *Chem. News*, **129** [3351] 35–36 (1924).

(*c*) Popp, *Annalen*, **156,** 63 (1870).

(*d*) M. E. Kopp, "Action of Alkaline Hyposulphites on Chromates of Potash and Ammonia," *Chem. News*, **11,** 16–19 (1865).

(*e*) E. Moles and F. Gonzales, "Ammonium Dichromate," *Anales soc. españ. fís quím*, **21,** 204–12 (1923); *Chem. Abs.*, **17** [18] 2999 (1923).

(*f*) S. S. Bhatanager, Brahm Prakash, and Abdul Hamid, "Magnetism and Molecular Constitution of Some Chromium Compounds," *Jour. Chem. Soc.* [London], **1938,** pp. 1428–34.

(*g*) Arthur Simon and Theodor Schmidt, "Oxides of Chromium," *Z. anorg. allgem. Chem.*, **153,** 191–218 (1926); *Ceram. Abs.*, **6** [1] 37 (1927).

(*h*) Kôtarô Honda and Také Soné, "Magnetic Investigation of Structure Changes in Iron and Chromium Compounds at Higher Temperatures," *Science Repts. Tôhoku Imp. Univ.*, **3** [1] 223–34 (1914).

(*i*) Ivan Scuukoff, "Magnetic Oxide of Chromium," *Compt. Rend.*, **146** [1] 1396–97 (1908).

(*j*) Traube, *Annalen*, **66,** 87 (1845).

(*k*) I. G. Ryss and A. I. Selyanskaya, "Thermal Dissociation of Chromium Trioxide," *Acta Physiochim.* [U.R.S.S.] **8,** 623–40 (1938); *Chem. Abs.*, **33** [17] 6692 (1939).

[2] (*a*) A. Cameron, E. H. Harbard, and A. King, "Nonstoichiometric Oxides: I, Oxides of Chromium," *Jour. Chem. Soc.* [London], **1939,** pp. 55–61.

(*b*) S. S. Bhatanager, A. Cameron, E. H. Harbard, P. L. Kapur, A. King, and Brahm Prakash, "Magnetic Susceptibilities of Metallic Oxides, with Special Reference to Those of Chromium and Manganese," *ibid.*, **1939,** pp. 1433–41; *Ceram. Abs.*, **20** [4] 104 (1941).

intermediate between $CrO_3$ and $Cr_2O_3$ were found whose compositions were between $CrO_{1.7}$ to $CrO_{1.9}$ and $CrO_{2.2}$ to $CrO_{2.6}$, which suggested the following scheme:

$CrO_3 \rightarrow CrO_{2.6}$ stoichiometrically at 220°C.
$CrO_{2.6} \rightarrow CrO_{2.2}$ nonstoichiometrically and gradually between 240° and 350°C.
$CrO_{2.2} \rightarrow CrO_{1.8}$ stoichiometrically and suddenly at 350°C.
$CrO_{1.8} \rightarrow Cr_2O_3$ gradually up to 550°C.

One fact on which all investigators agree is that $Cr_2O_3$ is the stable phase above 550°C.

The work of Milbauer[3] on the reversibility of this reaction is also interesting. He reported a partial conversion of $Cr_2O_3$ to $CrO_3$ with oxygen at 12 atmospheres of pressure at 300°C.; catalyzing the reaction with oxides of Ag, Mg, Zn, Cd, and Pb, the reversal was complete at 460°.

Blanc and Chaudron[4] report an oxidation of $Cr_2O_3$ to $Cr_5O_9$ between 450° and 500°C., which is dependent on the composition and pressure of the atmosphere. The glaze itself is also affected by the composition of the furnace atmosphere as shown by Watts.[5] Any alteration in the glaze surface will produce a variation in the final appearance of the color, which may be optical, chemical, or both. As the primary interest of this investigation is to study the effect of atmosphere on the color-producing substance, any variations in the glaze composition must be eliminated. Maintaining the compostion of the glaze constant would not accomplish this purpose because it would reduce the interpretation of the results to very narrow limits and it would remain impossible to infer whether a particular color were due to the effect of the atmosphere on the glaze, the coloring material, or both. After studying the behavior of the pigment itself, similar studies were carried out on glazes that contained these pigments.

## II. Treatment of Pigments

To study the pigments alone, samples of the green oxide, $Cr_2O_3$, were heated to 1000°, 1100°, and 1200° C. in a platinum combustion boat, which was placed in an electric resistance furnace. During this heating period, gases of predetermined composition were streamed at 10 cc. per second through the furnace. The time of treatment, unless otherwise specified, was 6 hr., that is, heating to the desired temperature in $3^1/_2$ hr. and holding constant for $2^1/_2$ hr. This length of time was necessary to insure uniformity throughout the samples.

## III. Treatment of Glazes

Two series of experiments were made as follows: (1) The treated pigments were added to a feldspathic glaze, applied to a vitreous floor-tile body, and fired under industrial conditions; and (2) a glaze containing untreated $Cr_2O_3$ was applied to the same body and fired under varying atmospheres. All of the batches were milled with 60% of water for 4 hr.

A feldspathic glaze, which matured at cone 10 (1265°C.), was used for both series; its empirical formula was as follows:

$$\left.\begin{matrix}0.3\ K_2O \\ 0.7\ CaO\end{matrix}\right\}\ 0.4\ Al_2O_3\quad 3.5\ SiO_2.$$

The batch formula was feldspar 47.3, whiting 19.9, clay (EPK) 7.3, and silica 25.5%.

The arrangement of apparatus used in the series is shown in Fig. 1.

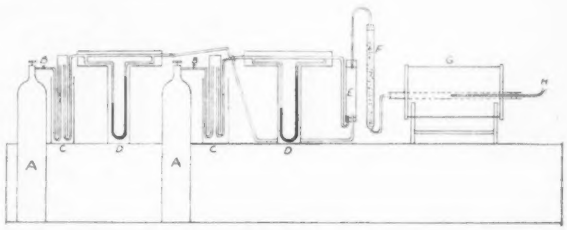


FIG. 1.—Arrangement of apparatus for passing mixtures of gases through furnace; *A*, cylinder gas; *B*, needle valve; *C*, reservoir; *D*, flowmeter; *E*, mixing tube; *F*, drying tube; *G*, furnace; *H*, thermocouple.

## IV. Color Measurement

### (1) Instrument and Preparation of Samples

Colors were measured with the Hunter multipurpose reflectometer.[6]

To measure the colors of the pigments on the reflectometer, it was necessary to present a surface about 2 by 3 in. in size. This was conveniently done by mixing the pigment with glycerin and spreading the resulting paste on a glass slide. The color, however, was so dark that the reflectance values were very low. To raise these values so that they would lie in the more sensitive range of the instrument,[7] zinc oxide was added. This method of dilution is standard practice.[8]

Five grams of zinc oxide and 5 cc. of glycerin were mixed with 0.5-gm. samples of each pigment, which raised the reflectance readings from about 5 to 30%. Only a negligible change in hue could be expected from this mixing, as shown by Merwin[9] in his work on tinting strength.

The mixtures of chrome, zinc oxide, and glycerin were thoroughly mixed on a glass plate, care being

[3] J. Milbauer, "Action of Oxygen on Metallic Oxides at High Temperature and Pressure," *Chem. Ztg.*, **40**, 587 (1916); *Chem. Abs.*, **10** [20] 2558 (1916).

[4] L. Blanc and G. Chaudron, "Transformations and Oxidation of the Sesquioxide of Chromium," *Compt. Rend.*, **182** [1] 386–88 (1926).

[5] A. P. Watts, "Effect of Furnace Atmospheres on the Quality of Certain Types of Glazes," *Jour. Amer. Ceram. Soc.*, **14** [6] 460–68 (1931).

[6] R. S. Hunter, "Multipurpose Photoelectric Reflectometer," *Jour. Research Nat. Bur. Stand.*, **25** [5] 581–618 (1940); R.P. 1345; *Ceram. Abs.*, **20** [7] 175 (1941).

[7] R. S. Hunter, Instructions for Use of Multipurpose Reflectometer. Communication not yet published.

[8] (*a*) H. D. Bruce, "Tinting Strength of Pigments," *Bur. Stand. Jour. Research*, **1** [1] 125–50 (1928); R.P. 7; *Ceram. Abs.*, **7** [12] 806 (1928).

(*b*) H. A. Gardner, Physical and Chemical Examination of Paints, Varnishes, Lacquers, and Colors. Laboratory Manual, Institute of Paint and Varnish Research, 1930.

[9] H. E. Merwin, "Optical Properties and Theory of Color of Pigments and Paints," *Proc. A.S.T.M.*, **17** [2] 494–530 (1917).

taken not to cause any grinding; the mixture was spread on a heavy, 4- by 4-in. glass plate and covered with a thin, colorless cover glass; strips of sheet metal were fastened to the corners of the base plate to insure a uniform layer of constant thickness; and the cover glass was held in place by spring clips. This arrangement presented an opaque film which gave reproducible measurements. The corrections usually necessary in this procedure need not be applied because they are the same in every case and will cancel out when comparisons are made.

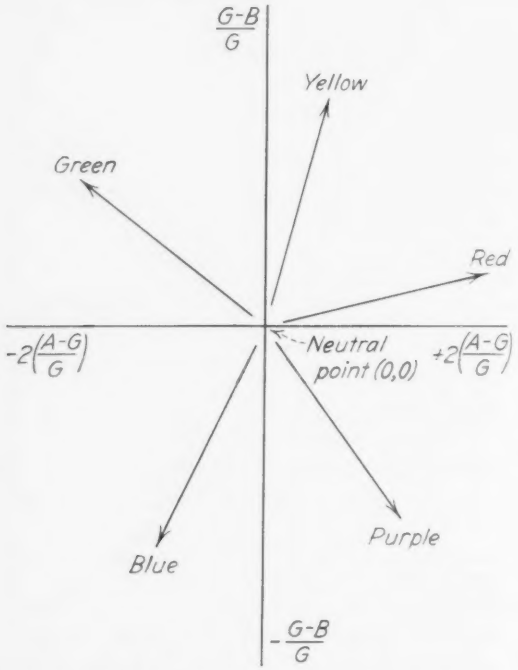


FIG. 2.—Color diagram for plotting data furnished by Hunter reflectometer.

## (2) Calculating and Plotting Colors

The simplest method of plotting the data furnished by the Hunter reflectometer is to plot the percentage of reflectance for light from each filter against the particular variable in question. This would give three separate curves, one each for the reflectance of the green, the amber, and the blue light, respectively. This method, however, does not show graphically the magnitude of the color change. To interpret the data in terms of the three attributes of surface color,[10] namely, hue, saturation, and lightness, Hunter[7] suggests plotting the difference between the reflectances of green and blue divided by the reflectance of green against twice the difference between amber and green divided by green as shown in Fig. 2. Hue is represented as an angular measurement and saturation as a distance from the neutral point.

The purpose in plotting the $2(A - G)/G$ values instead of the value $(A - G)/G$ is to spread the spectral hues more uniformly about the origin. This representation fixes two attributes of a colored surface, and the lightness would be represented in the third dimension.

If two colors have the same coordinates and the same reflectance for light passing through the green filter, they would be alike; colors having the same coordinates but different values of green reflectance would differ only in lightness. The distance between two different points on the diagram therefore represents the magnitude and type of color difference, and the distances from the origin shows the change in saturation.

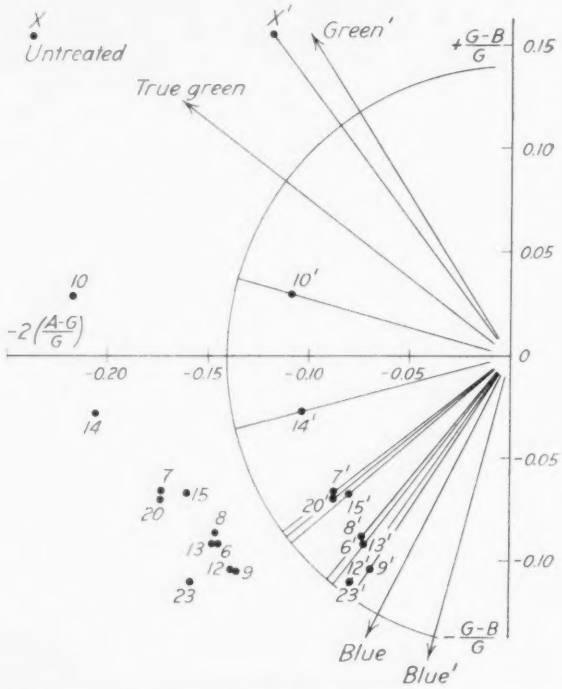


FIG. 3.—Portion of color diagram showing colors of pigments treated at 1200°C.

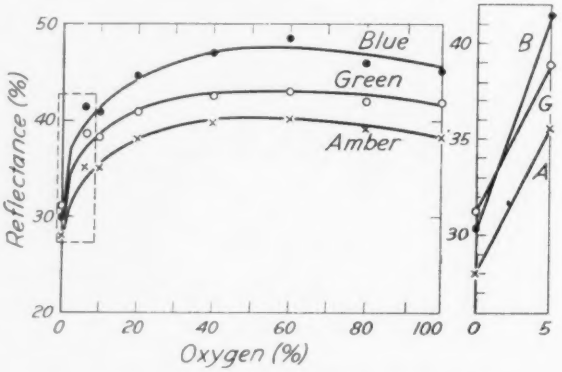


FIG. 4.—Reflectance of pigments treated at 1200°C.

[10] (*a*) D. B. Judd, "Color Systems and Their Inter-Relation." Symposium on Color of Inter-Society Color Council and Illuminating Engineering Society, Sept. 11, 1940.

(*b*) D. B. Judd and K. L. Kelly, "Method of Designating Colors," *Jour. Research Nat. Bur. Stand.*, **23** [3] 355–85 (1939); R.P. 1239; *Ceram. Abs.*, **19** [4] 85 (1940).

Both of these methods of plotting have been used as the basis of correlating the experimental data. The percentage of reflectance is plotted against the percentage of oxygen in the furnace atmosphere for each of the three temperatures at which the pigments were treated. The colors of each sample were also plotted as directed by Hunter,[7] and the change in hue, as shown by this scheme, was plotted as a function of the oxygen content of the atmosphere and also as a function of the temperature. The comparison in hue was made at equal saturation to compensate for the effect of any difference in particle size of the pigments. This extrapolation is shown in Fig. 3; colors plotted on the regular scale are designated by plain numbers; and the primed numbers have the same $(G - B)/G$ value but only one half the $2(A - G)/G$ value. This was done to give the same dimension in both directions. A circle was then drawn with the neutral point as the center, and lines were drawn from each primed value to this center.

The intersection of the value of untreated chromic oxide ($X'$) with the circle was taken as a reference point, and the distances from this point to the intersections of the other colors were taken as a measure of the change in hue. These values, taken from the curve with dividers, were plotted as ordinates against the oxygen content and the temperature of the furnace atmosphere. Because the size of the circle was arbitrary, all of the curves which follow were plotted on the same scale making it possible to go from any one figure to any other to compare magnitudes. All of the curves also bear the same relationship to each other.

The change in saturation with atmosphere was plotted by taking the distance from the origin to the particular color (plotted on the regular coordinates of Fig. 4) as ordinate and the composition of the atmosphere as abscissa.

## V. Experiments on Pigments

Table I records the treatment and resulting color measurements of each sample of chromic oxide. The chromic oxide used in all cases except run No. 23 was a good grade of ceramic chrome green; run No. 23 was made with pure chromic oxide prepared by heating c.p. ammonium dichromate and thoroughly washing and drying the resulting $Cr_2O_3$. All of the gases were of reagent quality.

The reflectance values for treated chrome versus percentage of oxygen are plotted on Figs. 4 and 5. These curves represent only the values of pigments treated in oxygen and nitrogen mixtures for 6 hr. at 1200°, 1100°, and 1000°C., respectively.

## VI. Pigment Color Changes

### (1) In Oxygen-Nitrogen Atmospheres

The hue change caused by heating in oxygen was generally from green toward blue. Higher temperature and higher oxygen content made the change much greater. In all cases, the first increment of oxygen caused the largest change which, as expected from the reflectance curves, approaches a constant value. The

TABLE I

| Run No. | Temp. (°C.) | Time (hr.) | $O_2$ (%) | Other gas | Reflectance (%) | | | $\frac{2(A-G)}{G}$ | $\frac{G-B}{G}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Green | Amber | Blue | | |
| 1 | 1200° | 6¼ | 100 | | 42.6 | 40.0 | 47.7 | −0.122 | −0.120 |
| 2 | " | 3 | 100 | | 40.3 | 37.5 | 44.1 | −0.139 | −0.094 |
| 3 | " | " | 0 | $N_2$ | 29.5 | 26.2 | 27.8 | −0.224 | +0.058 |
| 4 | " | " | 0 | " | 29.6 | 26.2 | 26.8 | −0.230 | +0.095 |
| 5 | " | " | 100 | | 35.2 | 31.8 | 36.8 | −0.193 | −0.031 |
| 6 | " | 6 | 100 | | 41.4 | 38.4 | 45.2 | −0.145 | −0.92 |
| 7 | " | " | 10 | $N_2$ | 38.3 | 35.0 | 40.9 | −0.173 | −0.067 |
| 8 | " | " | 20 | " | 41.2 | 38.2 | 44.8 | −0.146 | −0.087 |
| 9 | " | " | 40 | " | 42.5 | 39.6 | 47.0 | −0.136 | −0.106 |
| 10 | " | " | 0 | " | 31.2 | 27.8 | 30.3 | −0.218 | +0.029 |
| 11* | " | " | 0 | " | 36.9 | 33.4 | 38.9 | −0.190 | −0.054 |
| 12 | " | " | 60 | " | 43.4 | 40.4 | 47.9 | −0.138 | −0.104 |
| 13 | " | " | 80 | " | 42.2 | 39.1 | 46.1 | −0.147 | −0.092 |
| 14 | " | " | 0 | $CO_2$ | 34.0 | 30.5 | 34.9 | −0.206 | −0.026 |
| 15 | " | " | 10 | " | 38.7 | 35.6 | 41.3 | −0.160 | −0.067 |
| 16 | 1000 | " | 20 | $N_2$ | 30.8 | 26.7 | 29.5 | −0.208 | +0.042 |
| 17 | " | " | 100 | | 31.3 | 27.9 | 30.0 | −0.218 | +0.042 |
| 18 | " | " | 0 | $N_2$ | 30.5 | 27.1 | 28.4 | −0.223 | +0.069 |
| 19 | 1100 | " | 20 | " | 34.5 | 31.0 | 34.8 | −0.203 | −0.009 |
| 20 | 1200 | " | 5 | " | 39.0 | 35.6 | 41.7 | −0.174 | −0.069 |
| 22 | " | " | 0 | " | 29.8 | 26.6 | 28.3 | −0.214 | +0.050 |
| 23 | " | " | 100 | | 41.6 | 38.3 | 46.2 | −0.159 | −0.110 |
| 24† | " | " | 0 | $N_2$ | 45.8 | 42.8 | 51.2 | −0.131 | −0.118 |
| 25‡ | " | " | 0 | " | 45.6 | 42.5 | 50.9 | −0.136 | −0.116 |
| 36 | 1100 | " | 100 | | 33.8 | 30.2 | 34.5 | −0.214 | −0.021 |
| 37 | " | " | 40 | $N_2$ | 33.4 | 29.8 | 33.9 | −0.216 | −0.015 |
| 38 | " | " | 80 | " | 33.7 | 30.3 | 34.2 | −0.202 | −0.015 |
| 39 | " | " | 0 | " | 30.5 | 27.2 | 28.9 | −0.216 | +0.052 |
| 40 | 1000 | " | 40 | " | 31.7 | 28.3 | 30.5 | −0.215 | +0.038 |
| 41 | " | " | 80 | " | 30.7 | 27.4 | 29.3 | −0.215 | +0.046 |
| Values for untreated $Cr_2O_3$ | | | | | 29.6 | 26.4 | 25.3 | −0.216 | +0.145 |

* Run of sample treated in No. 5. † Run of sample treated in No. 9. ‡ Run of sample treated in No. 24.

colors for each temperature are shown on Hunter's[7] diagram in Figs. 3, 6, and 7.

The hue change as a function of the oxygen content is shown for all three temperatures in Fig. 8. Figure 9 shows the effect of temperature for atmospheres of the following composition: 100% of $N_2$, 20% of $O_2$ to 80% of $N_2$, and 40% of $O_2$ to 60% of Na.

### (2) Effect of Carbon Dioxide

Only two runs were made with carbon dioxide (Nos. 14 and 15) at 1200°C. The positions of the colors of the resulting pigments may be seen in Figs 3 and 8.

### (3) Change in Color Saturation

The change in color saturation is a function of the oxygen content of the atmosphere for 1000° and 1200°C. The ordinates of curves that would show this change are the distances from the neutral points to the designated colors in Figs. 3 and 7. A sharp drop in saturation was caused by heating with the first increment of oxygen, the change becoming constant with increasing amounts. It must be again noted that heating in 100% of $N_2$ produced a relatively small but significant change and that the change is more extreme at the higher temperatures. This decrease in saturation indicates that higher temperature and oxygen content tend to increase the particle size of the pigments. It shows that a given weight of white pigment can cover a constant weight of chrome pigment more effectively. Considered from the standpoint of color mixing, it shows that the ratio of the amounts of white to green surface increases. With constant weights of each in all cases, it indicates that the chrome particles must have become larger during treatment.

### (4) Effect of Time and Reheating

In some of the early runs, periods of time shorter than six hours were used, but the colors varied from one part of the sample to another. Although these runs were not regular, they showed qualitatively that the change increased with time. A comparison of two such values is shown in Fig. 10 by points Nos. 4 and 22; No. 4 was 100% of $N_2$ at 1200°C. for 3 hr. and No. 22 was given the same treatment for 9 hr.

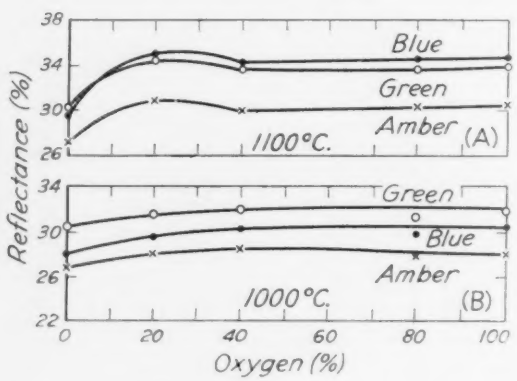


FIG. 5.—(*A*) and (*B*).

Point Nos. 5, 11, 9, 24, and 25 are also plotted on Fig. 10. No. 5 represents the color of $Cr_2O_3$ after being heated at 1200°C. for 3 hr. in an atmosphere of 100% of

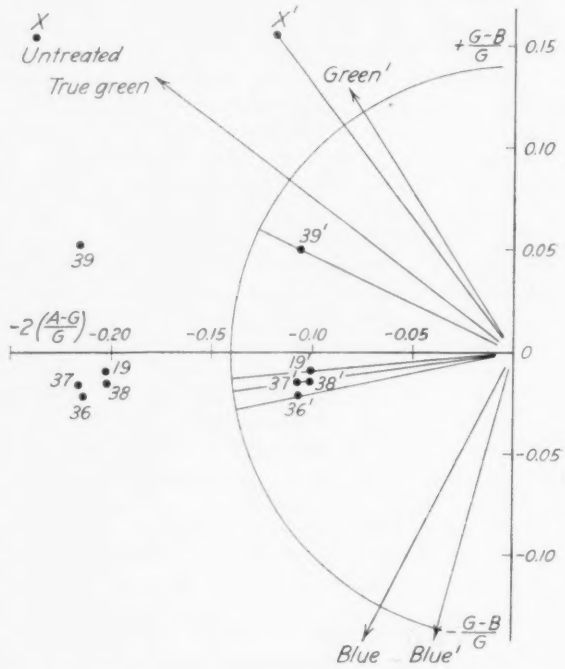


FIG. 6.—Portion of color diagram showing colors of pigments treated at 1100°C.

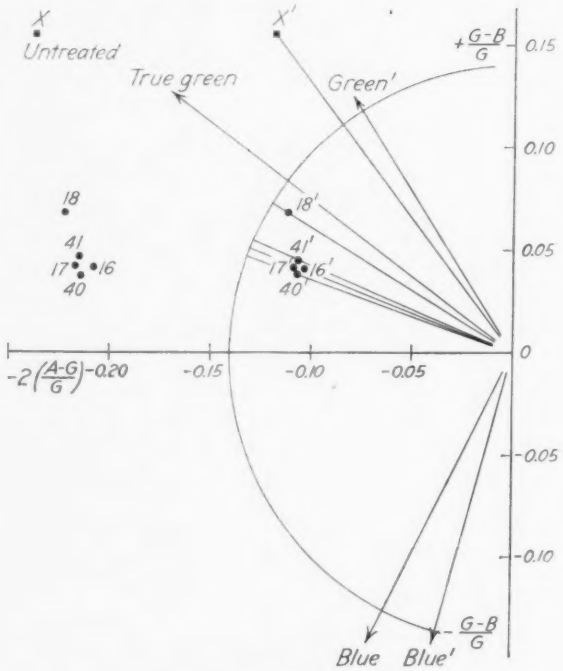


FIG. 7.—Portion of color diagram showing colors of pigments treated at 1000°C.

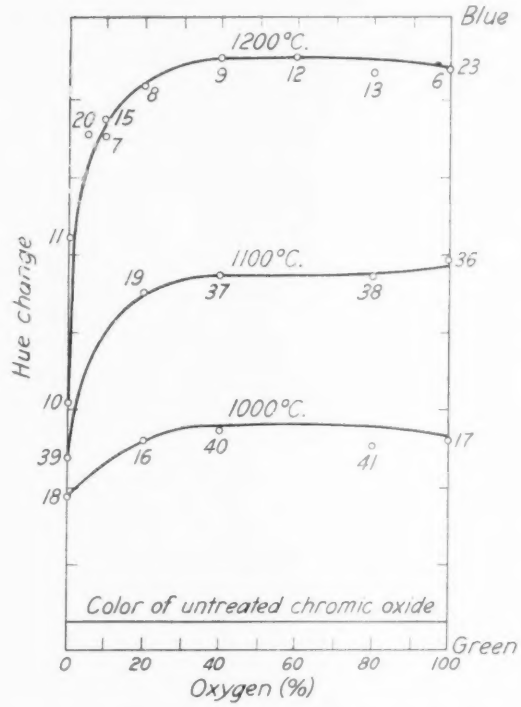


FIG. 8.—Color change of pigment plotted vs. percentage of oxygen in atmosphere.

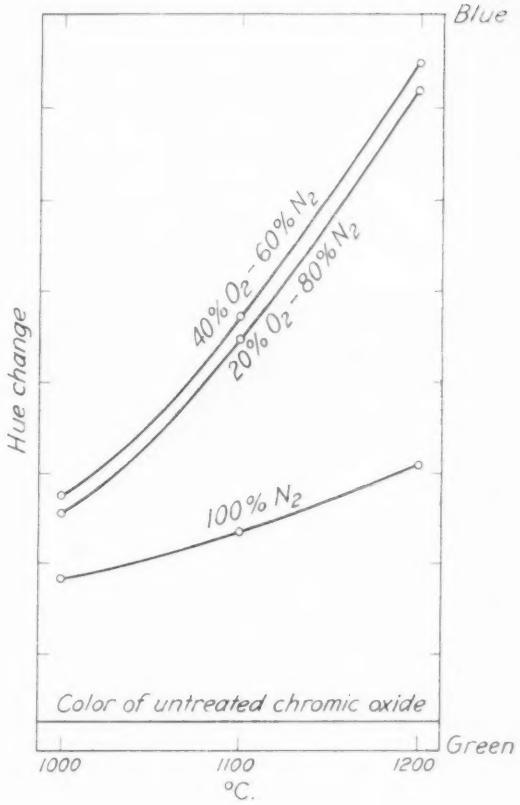


FIG. 9.—Color change of pigment plotted vs. temperature.

$O_2$; No. 11 shows the color of this sample after it was reheated to 1200°C. for 6 hr. in an atmosphere of 100% of $N_2$; No. 9 shows the color after treatment at 1200°C. for 6 hr. in 40% of $O_2$ and 60% of $N_2$; No. 24 shows the color of No. 9 after it was reheated to 1200°C. in 100% of $N_2$ for 6 hr.; and No. 25 shows the color of No. 24 after another 6-hr. heating in nitrogen. These observations show that the color change continues in the same direction on reheating although to a smaller degree even in the absence of oxygen. They also show that, although oxygen is important in producing the color change, it is not the only factor involved.

## (5) Volatility

A noticeable effect (in addition to the color change) of heating in oxygen or oxygen-rich mixtures was volatility of the chrome. This was particularly apparent when the treatment was carried out in a glazed porcelain combustion boat (runs Nos. 1, 2, 3, and 4). When heated in nitrogen, the boat remained clean and white; but when oxygen was used, the walls and outer surface of the boat were covered with a black and brown deposit. The black condensation was on the inside wall of the boat just above the mass of pigment itself and was fairly heavy. The brown deposit was more like a discoloration on the outside walls of the boat.

## (6) Change of Particle Size

The heat-treatment reduced the amount of fine particles in all cases. This was inferred from the decrease in color saturation and also was observed qualitatively

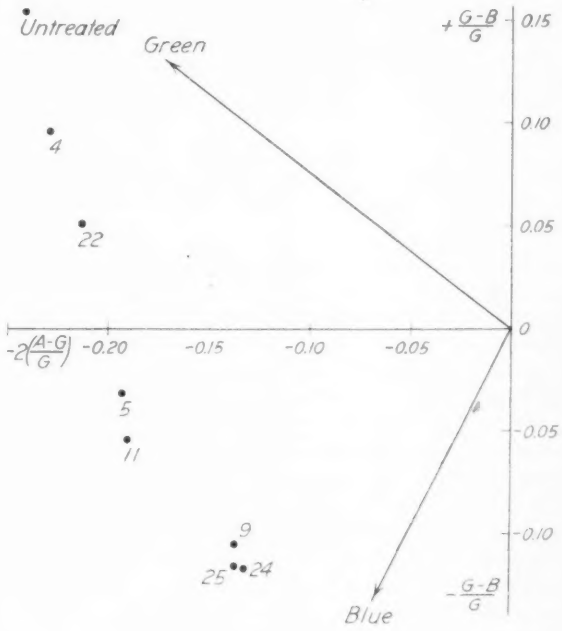


FIG. 10.—Portion of color diagram showing colors of pigments treated at 1200°C. for different lengths of time.

TABLE II

| Run No. | Pigment (% of $O_2$) | Green | Amber | Blue | $\frac{2(A-G)}{G}$ | $\frac{G-B}{G}$ |
|---|---|---|---|---|---|---|
| 22 | 0 | 32.3 | 27.4 | 21.4 | −0.303 | +0.337 |
| 20 | 5 | 29.0 | 25.0 | 21.4 | −0.276 | +0.262 |
| 7 | 10 | 28.6 | 24.7 | 21.9 | −0.273 | +0.234 |
| 8 | 20 | 25.1 | 21.6 | 18.9 | −0.279 | +0.247 |
| 9 | 40 | 24.4 | 21.1 | 18.7 | −0.271 | +0.233 |
| 12 | 60 | 25.3 | 21.9 | 19.7 | −0.269 | +0.222 |
| 13 | 80 | 25.5 | 22.2 | 19.8 | −0.259 | +0.224 |
| Untreated chrome ($X$) | | 39.0 | 33.0 | 25.7 | −0.308 | +0.341 |

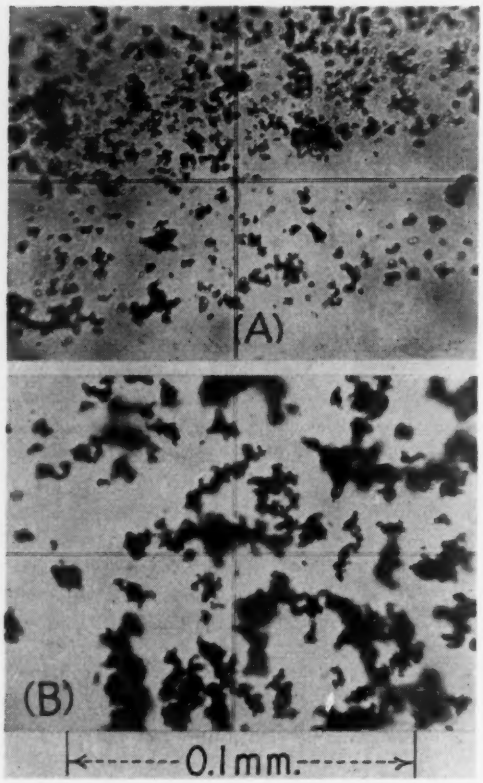


FIG. 11.—($A$) Microphotograph of untreated chromic oxide; ($B$) microphotograph of chromic oxide after heating at 1200°C. in oxygen.

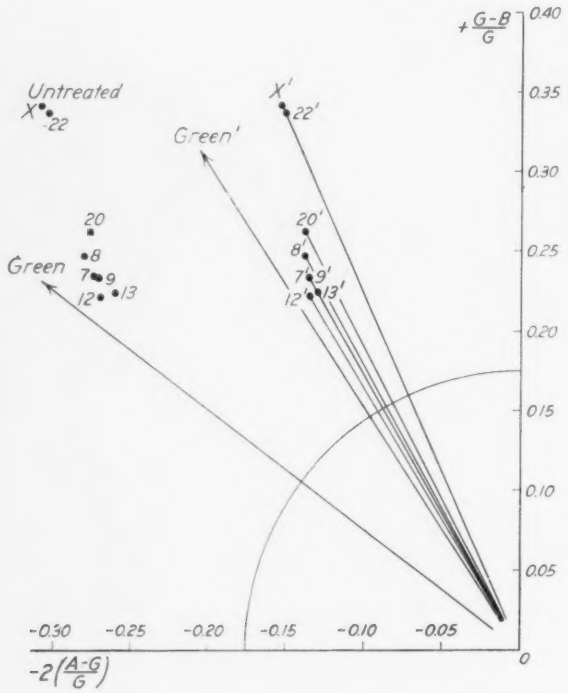


FIG. 12.—Color diagram showing colors of feldspathic glazes containing pigments treated at 1200°C.

| Run No. 6 | Reflectance (%) Green | Amber | Blue |
|---|---|---|---|
| Unfractionated samples | 41.4 | 38.4 | 45.2 |
| Finer than 40μ | 41.4 | 38.4 | 45.4 |

by noting the rate of sedimentation in water. Photomicrographs (Fig. 11 ($A$) and ($B$)) of untreated chromic oxide and of a sample showing a large color change (run No. 13) verify this observation. The untreated chromic oxide may be seen to consist of very fine and uniform particles; the larger spots are clusters of fine particles which could not be brought into sharp focus under the high magnification used. In the treated sample (Fig. 11 ($B$)), most of the fine particles have disappeared and many large ones have formed. These larger crystals were bright green under the microscope.

This change in particle size did not introduce any error into the color measurements, and little or no measurable difference in color was produced by the maximum difference in particle sizes. A typical example of the reflectances of two different size ranges of the same pigment is as follows:

The difference that does exist is well within experimental error, which shows that the color of each sample was uniform.

### (7) Effect of Grinding

A sample of one of the pigments which had undergone a large color change was ground in an agate mortar, and the color was again measured. The color was shifted back toward the original green of untreated chromic oxide.

## VII. Experiments on Glazes

### (1) Glazes Containing Treated Pigments

Three per cent of the pigments produced in runs Nos. 22, 7, 8, 9, 12, 13, and 20 (see Table I) and untreated chrome were mixed with portions of the white feld-

spathic glaze, applied to a vitrified 4- by 4-in. floor tile, and fired 17 hr. to cone 10 (1280°C.) in a direct-fired gas kiln. Because the reflectance values were rather low, being of the order of 10 to 15%, an aperture on the instrument was used which cuts the intensity of the comparison beam by 50%. The values of these reflectances, the color coordinates, and the oxygen content of the atmosphere in which the pigments were originally treated are summarized in Table II.

The colors of these glazes are plotted in Fig. 12. The hue change as a function of the oxygen content of the atmosphere used in treating the pigments is shown in Fig. 13. These figures are plotted on the same scale as all of the other color data.

### (2) Glaze Containing Untreated Pigments

Three per cent of untreated chromic oxide was added to the same base glaze used in the preceding experiments, and samples of this glaze were fired to maturity (1265°C.) under atmospheres of different oxygen and nitrogen content. No color measurements could be made of these results because the furnace (see Fig. 1) was not large enough to hold a sample of sufficient size to cover the opening of the reflectometer. The glaze was applied on 4- by $1/2$-in. strips of the same body as used in the preceding experiment, and the following atmospheres were maintained:

| Run No. | $O_2$ (%) | $N_2$ (%) |
|---|---|---|
| 27 | 100 | 0 |
| 28 | 0 | 100 |
| 29 | 10 | 90 |
| 30 | 50 | 50 |
| 33 | 70 | 30 |
| 44 | 20 | 80 |

The color change produced was the reverse of that caused by heating the pigments alone. The sample heated in 100% of oxygen was a light yellow-green of relatively low saturation. The sample heated in 100% of nitrogen was a strong dark green. Atmospheres in between these extremes yielded intermediate colors. The greatest difference between samples treated under atmospheres successively richer in oxygen was after the first 10% of increment; above 20% of oxygen, there was little visible difference. The same phenomenon of volatility noted when the pigments were treated alone in oxygen was also found in this series of glazes. Discoloration of the edges of all of the pieces heated in atmospheres containing oxygen was observed. A reaction causing a brown discoloration at the body-glaze interface was also observed in all samples heated in oxygen. This reaction was entirely absent in the sample heated in 100% of nitrogen. Figure 14 (*A*) and (*B*) shows this difference clearly; there are also apparently more or finer-grained colored particles in the glaze fired in oxygen than in the one fired in pure nitrogen. The particles in the nitrogen-fired glaze were fine and distinct, similar to those of the nitrogen-treated pigment (Fig. 14 (*A*)). The colored particles in the oxygen-fired glaze were hazy and larger in size; they were more uniformly distributed throughout the glaze, and no distinct crystal structure could be observed.

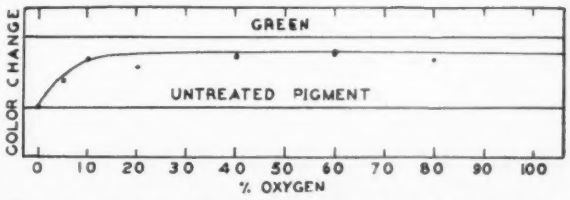


FIG. 13.—Color change of glazes containing treated pigments.

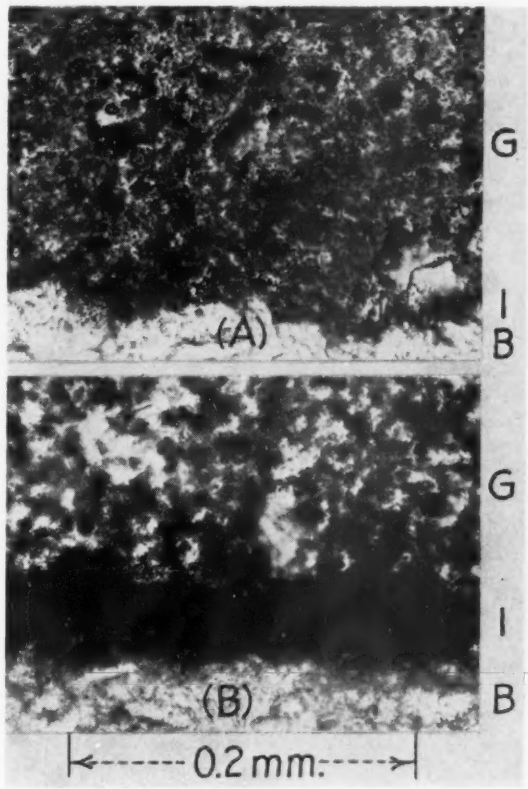


FIG. 14.—(*A*) Microphotograph of glaze fired in nitrogen; (*B*) microphotograph of glaze fired in oxygen. *G*, glaze; *I*, interface; and *B*, body.

## VIII. Conclusions and Discussion

When chromic oxide is heated, the color is changed toward blue. This color change is accompanied by an increase in the particle size, the larger particles apparently growing at the expense of the finer.

An increase in the oxygen content of the atmosphere as well as in temperature and heating time effect an increase in the magnitude of the change, the oxygen content being the most critical. The largest change with successive increments of oxygen is produced by the first 5%, with further additions approaching a constant value. These factors also favor the increase in particle size by distillation.

It would be expected normally that the increase in time and temperature would favor this size change because the fact is well established that finer particles of a given substance exert a higher vapor pressure than

the coarse particles. The increase in the magnitude of this phenomenon in the presence of oxygen is a specific property of the two substances in question; even the first 5% increment of oxygen causes a major change, and it shows that a reaction has taken place. The present knowledge of the behavior of chromium oxides is not consistent enough to permit any positive conclusions as to the mechanism of the reaction to be drawn. As pointed out previously, there is general agreement that $Cr_2O_3$ is the only stable oxide above 500°C. Milbauer[3] claimed that some oxidation of $Cr_2O_3$ to $CrO_3$ occurred at a pressure of 12 atmospheres of oxygen, but he made no mention of the stability of the resulting product. The significant thing in his report, however, is that oxidation of chromic oxide can occur.

These observations suggest that the mechanism of the change encountered in this research involves the formation of some intermediate higher oxide which reverts back to the stable $Cr_2O_3$ by the time the sample cools to room temperature. On heating in the presence of oxygen, this oxide forms on the surface of the particles. Because it is more volatile than $Cr_2O_3$, the oxide evaporates; some condenses on the larger grains, and the remainder passes off in the stream of gas circulating through the furnace. This would account for the decrease of the number of fine particles and the increased magnitude of this effect with greater partial pressures of oxygen. This mechanism is also consistent with the observed properties of the color change of the pigments. On this basis, the change in hue may be attributed to the layer of $Cr_2O_3$ deposited on the original particles, and its different color characteristics are due to a difference in structure.

The best evidence in this research leading to the conclusion that a layer of $Cr_2O_3$ of different color is deposited is the fact that even when the samples are heated in nitrogen a smaller but similar color change is produced than is obtained in those treated with oxygen. This is further established by the observation that when a highly altered pigment (runs Nos. 5 and 9) is reheated in nitrogen the color change is slightly accentuated rather than reversed. If some higher oxide were still present after the first heating in oxygen, it would be unstable and tend to decompose on reheating in nitrogen to the temperatures employed in this research. This would have shown itself, experimentally, as a reversal of the color change in hue.

The idea of a surface reaction was brought out by the fact that grinding an oxygen-treated pigment tends to change the color back toward that of untreated chrome. This color change might suggest the idea that particle size alone may be the deciding factor in view of the method of color measurement, but this conclusion has been shown to be untrue. A comparison was made between the chromic oxide used in these experiments with some c.p. chromic oxide. The latter material was much finer in size than the regular chrome, and when they were heated in oxygen, both samples displayed the same change in hue although the pure chrome was still finer grained. This was shown by the fact that the pure chrome produced a more saturated color (Figs. 3 and 8, run No. 23) when it was mixed with zinc oxide and glycerin than did the regular chrome in run No. 6.

### (1) Colors of Glazes Containing Treated Pigments

Before inclusion in the glaze, the pigments went from green toward blue with increasing oxygen in the atmosphere. When the pigments were included in the glaze, all of the colors fell on the yellow side of the spectrum, but they approached green with increasing oxygen treatment of the pigment. Considering the spectrum as a whole, this latter change is still a shift toward blue. A brown discoloration was noted at the body-glaze interface of all pieces fired in this series; this will be discussed more fully in the next section.

### (2) Color Changes in Glazes Containing Untreated Chromic Oxide

In the foregoing experiments, the pigments were treated first and then incorporated in a glaze, all glazes receiving the same treatment. In this series, the untreated pigment was put into the same glaze, and the glazes were fired under atmospheres of varying oxygen and nitrogen content. The color changes in this latter case were exactly the reverse, going from strong dark green to light yellow-green as the oxygen was increased. The reactions in this case are much more complicated because the glaze contains substances (CaO, $K_2O$, $SiO_2$, and $Al_2O_3$) which are known to react with $Cr_2O_3$. Athavale and Jatkar[11] and Nargund and Watson[12] pointed out the complexities of the system CaO–$Cr_2O_3$–$O_2$ in their studies of the dissociation pressures of calcium chromate. Many different compounds are present in this three-component field, but no data on their colors are available. It is known, however, that fusion of chromic oxide with calcium oxide and silica produces a light green mass, which is used as a ceramic pigment.

All that may be inferred from this research is that the reaction, whatever it might be, is enhanced by increasing the amount of oxygen in the furnace atmosphere during firing. The glaze fired in nitrogen, on the basis of visual color examination, seemed to have undergone no reaction other than the fusion of the ingredients. Colorimetrically, the chromic oxide seemed to have remained unchanged. This was shown by the fact that the nitrogen-treated glaze was almost exactly the same color as a sample of untreated chrome mixed with Canada balsam. The glaze in oxygen was decidedly different.

There was almost no volatility of the chrome when the glazes were treated in nitrogen but a definite vaporization was noted when oxygen was used. This could be seen by the brown discoloration on the unglazed areas of the tile and at the body-glaze interface.

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[11] V. T. Athavale and S. K. K. Jatkar, "Reactions of Chromates at High Temperatures: III, Decomposition of Calcium Chromate," *Jour. Indian Inst. Sci.*, **20A** [8] 55–66 (1937); *Ceram. Abs.*, **19** [1] 30 (1940).

[12] K. S. Nargund and H. E. Watson, "Reactions of Chromates at High Temperatures: II, The System Lime–Chromium Oxide–Oxygen," *Jour. Indian Inst. Sci.*, **9A**, 149–67 (1926); *Ceram. Abs.*, **6** [10] 475 (1927).

This same idea of volatility may then be used to interpret the changes in the glazes; chrome is oxidized and vaporized as discussed previously. In the glaze, however, instead of redepositing on other chrome particles (of which relatively few are present), it either deposits on or reacts with other constituents of the glaze. When the glaze components fuse to form a glass, no further change occurs. This was shown when a nitrogen-fired glaze was reheated in an atmosphere of oxygen and no change was observed. This vaporization accounts for both the increased reaction at the interface of the body and glaze and the greater uniformity of distribution of colored particles in the oxygen-fired glazes (Fig. 14 (*A*) and (*B*)). The gradual shading off and haziness of the reaction zone between the body and glaze indicates vapor penetration.

From this viewpoint, it is possible to interpret the changes observed in the glazes that contained the pigments previously treated. The shift and decrease of the color changes of these samples as compared with those of the pigments may be regarded as an approach to an average or mean value of two opposing tendencies. The hue shifts toward the blue when the chrome is treated separately with oxygen. Treating a chrome glaze tends similarly to shift the hue in the opposite direction. When the treated pigments are fired in a glaze, both effects operate as long as oxygen is present in the firing atmosphere. In normal ceramic firings, oxygen is usually present, and the smaller the oxygen content of the glaze-firing atmosphere, the more stable will be the color of the glaze.

**Acknowledgment**

This work was done in the Department of Ceramics, Rutgers University, under the Edward Orton, Jr., Ceramic Foundation Fellowship. The writer wishes to make acknowledgment to George H. Brown, Chairman of his Dissertation Committee, Armin W. Helz, and Laurence E. Kane for their personal interest and helpful advice during the course of this research; and also to Campbell Robertson for his suggestions in initiating the problem.

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# CERAMIC HISTORY

## THE BACKGROUND OF DEDHAM POTTERY*

By J. Milton Robertson

James Robertson, the fourth in line of a family of Scotch potters, arrived in this country in the old sailing vessel, Lord Mulgrave, in 1853, at what was then known as Roundabout, New Jersey (now Sayreville). With him came his wife, daughter, and three of his four sons, Alexander W., George W.,[1] and Hugh Cornwall Robertson. The latter was the founder of Dedham Pottery.

The father, after working for a short time in a pottery at Roundabout, took his family to East Boston, Massachusetts, where he entered into partnership with Nathaniel Plympton. The firm was known as the Plympton & Robertson Pottery Company, and the plant was located on Condor Street. They made white or yellow crockery from a clay brought from New Jersey by boat. The records of the Ninth Exhibition of the Massachusetts Charitable Mechanics Association in September, 1860, state that the firm was awarded the third prize for its teapots and tableware, and the judges commented that the ware compared well with Bennington ware.[2]

Prior to 1866, Alexander Robertson started a pottery in an old varnish factory at the corner of Willow and Marginal streets in Chelsea. This location was chosen because of its close proximity to quantities of red clay, most of which came from the Old Carey Pit near Powder Horn Hill. The type of ware made from this clay was mostly flowerpots, ferneries, and beanpots. Little or no decoration was used at first.

In 1867, Hugh joined his brother, Alexander, and they operated under the title of A. W. & H. C. Robertson, and from that time on glazed decorations were applied to the ware. Desiring to produce a type of ware with more artistic appeal, they copied the early Greek, Roman, and Egyptian vases, similar to those of the Cesnola Collection, in the red bisque with black decorations and with modeled decoration in high relief.

Their next advanced step was to produce ware that became known as Chelsea faience. It was a glazed ware, with decorations modeled in relief, which also included hand-hammered and appliqué types, after the order of Limoges.

James Robertson retired from the firm of Plympton & Robertson in 1872 and joined with his sons in the Chelsea Pottery, where, besides continuing the faience ware, he produced what is believed to be the first pressed clay tile made in the United States, to which the faience glazes were easily adapted. In 1878, they were awarded first prize at the Massachusetts Charitable Mechanics Association Exhibition in the name of James Robertson & Sons. The firm name at this time was Chelsea Keramic Art Works, Robertson & Sons. Many of the decorations on the vases and tile were from the hand of John G. Low, a young Chelsea artist, who later started the Low Art Tile Works on Broadway, Chelsea.

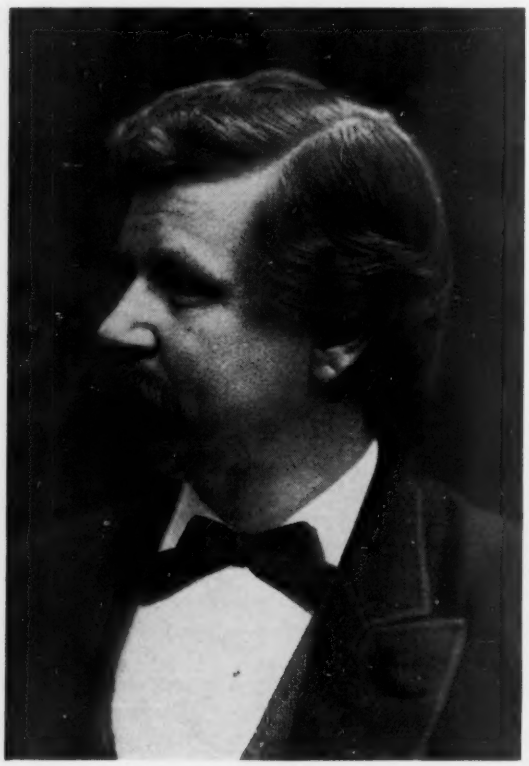
* From an illustrated catalogue published by the Dedham Pottery on January 1, 1938.

[1] George W. Robertson started the pottery which became the Robertson Art Tile Company.

[2] The pottery industry was flourishing in New England at this time and competition was keen. A list of potteries and the type of ware each produced was published in the May, 1939, *Bulletin*, pp. 181–85.

James Robertson died in 1880, and, in 1884, Alexander went to California to engage in pottery making. Hugh continued alone on further experiments, one of which was the production of a fine apple green.

At the Centennial Exhibition in Philadelphia in 1876, Hugh saw the Korean Exhibit, including the Chinese crackle and dragon's blood vases, which so intrigued him that, on his return to Chelsea, he set out to produce this red. The final result was the production of Chinese dragon's blood, which was the same as that made in the Ming Dynasty. This red is called sang de boeuf by the French and oxblood by the English. The cost of these experiments left Hugh penniless, but during the stages of experimentation for the red color, he discovered the process of making crackleware. At first, this crackle was successfully used on vases and tall pieces only; it was necessary to experiment further (until 1886) before the crackle could be used for flatware.



**Hugh Cornwall Robertson**

With the old Pottery and its equipment in a worn-out condition and the Pottery shelves filled with beautiful examples of his efforts and no market for them, Hugh was forced to close up in 1889.

In 1891, a group of Boston ladies and gentlemen formed a company which supplied sufficient funds to reopen the Pottery with Hugh Robertson as manager; it was called the Chelsea Pottery, U.S.A. Among these benefactors appear the names of Arthur Astor Carey, A. Wadsworth Longfellow, Horace D. Chapin, Joseph Linden Smith, Sarah W. Whitman, Mrs. Jack Gardner, William Sturgis Bigelow, J. Templeman Coolidge, and R. Clipston Sturgis.

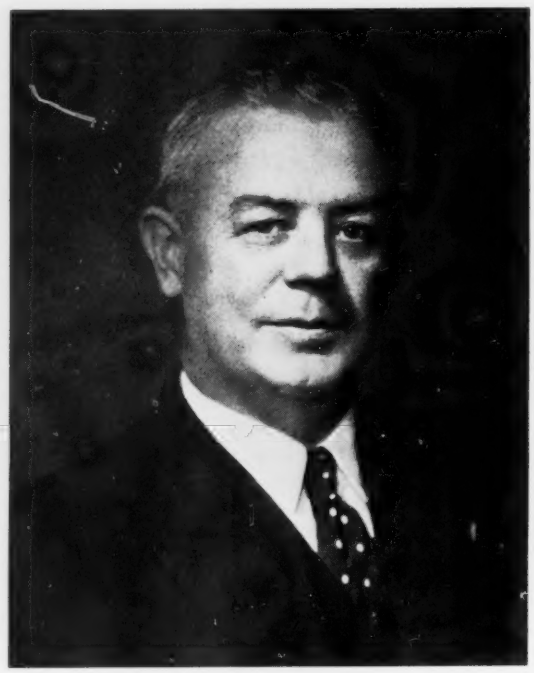
At this juncture, William A. Robertson, Hugh's son, who had been growing up with the Pottery, was engaged to take charge of the firing. The development of a crackleware with blue inglaze decoration was now undertaken. The decorating of the ware was under the direction of Charles E. Mills, a Boston artist, who, besides painting new designs, adapted old ones into successful patterns.

Because of the local dampness which affected the kilns, it became apparent that Chelsea was not suited for the production of crackleware and a new location was sought. Dedham was the final selection for the new plant; construction was started in 1893, operations were transferred in the latter part of 1894, and production was started in 1895.[3]

In Dedham, besides the making of crackleware, Hugh produced many excellent vases with a high-fired glaze on a hard-fired base, all hand thrown. Some of these, together with pieces of dragon's blood or Robertson's blood, as he frequently called it, received one of the highest awards at the Paris and San Francisco World's fairs and the Gold Medal at the St. Louis World's Fair.

Hugh Robertson always considered the peak of his success two dragon's blood vases which became known as the "Twin Stars of Chelsea" and which are now stored in a bank vault after many years of traveling throughout the United States on exhibition.

Born in Wolverton, County Durham, England, July 4, 1844, Hugh Cornwall Robertson died in Dedham, Massachusetts, on May 26, 1908. He held the degree of Master Craftsman and Medalist, which was conferred on him by the Society of Arts and Crafts, Boston, of which he was a member from its inception. His years of effort and



**J. Milton Robertson, Superintendent**

[3] The name of the Pottery was changed from Chelsea to Dedham in 1895.

struggle to attain his ambition, as E. H. Sothern, the famous actor, once said, were "comparable to the hardships experienced by Palissy."

His son, William, continued the manufacture of the crackleware, though considerably handicapped by injuries received in an explosion of a test kiln at the Pottery in 1904; his hands were disfigured to the extent that he was prevented from carrying on the modeling of his father.

J. Milton Robertson, son of William A. Robertson, and the seventh generation of this family of potters, here entered in the footsteps of his father and grandfather, and with the aid of better raw materials is at present producing the famous crackleware in a larger variety of shapes, but still holding to the conventional types that were approved by the patrons of Hugh C. Robertson.

## ROBERTSON ART TILE COMPANY*

### Fiftieth Anniversary, 1890–1940

Fifty years ago this month (December, 1940), a charter of incorporation was granted by the State of New Jersey to the Robertson Art Tile Company "to manufacture art tile and pottery of all kinds."

Arthur D. Forst, who had not yet reached his twenty-fifth birthday, was made president, and he guided the Company continuously until February, 1929. He had completed his education at Princeton University in 1888; he married in 1889 and inherited a modest sum of money on the death of his father—but no job.

**Arthur D. Forst**

A small pottery had been started across the river from Trenton early in 1890 and, needing funds to complete the buildings and put it into operation, it attracted his attention with the result that he invested sufficient funds to complete the buildings, and, on December 22, 1890, incorporation was completed with Mr. Forst as president. The name of Robertson was given to the Company in deference to George W. Robertson, the sturdy English potter who had settled in New England in 1853 and with his brother had started a pottery near Boston. It was he who had come early in 1890 to Morrisville, Pennsylvania, and had selected the site and had built the first small buildings and kilns but needed additional capital to go into production. He became vice-president of the Company in charge of the manufacturing, with the aid of his son.

**D. Parry Forst, President**

A tragic accident occurred within less than three years after this beginning. Mr. Robertson's son, James Robertson, was killed at a railroad crossing half a mile from the Pottery. The father was deeply affected by this turn of events and his health declined. In a short time, he sold out his interest and moved subsequently to California, where he lived in retirement for many years.

The Company, however, continued to operate with many growing pains and suffering many vicissitudes during the development as pioneers of a new American industry; it survived the hard times of 1893–1894, the unsettled conditions resulting from the Spanish-American War of 1898–1899, the panic years of 1907–1908, the first World War (especially from 1917 to 1919), the depression of 1921–1922, and the worst depression years in American history from 1930 to 1940. Not once in all these fifty years was the Company's operation ever interrupted.

In this period of fifty years, the Company never defaulted an obligation or changed the essential ownership of its stock. Today it has no debt, no encumbrances.

Its increase in size from the first small "pottery" to the present modern manufacturing plant is a story of steady growth in the facilities of production from a few thousand square feet per year in 1890 to approximately five million square feet per year in 1940. Many of the present-day

* From *Flooring*, December, 1940.

accepted methods of manufacture were first developed and introduced in the industry at the Company's plant.

The first swimming pool in the United States to be lined with ceramic mosaic tile was pioneered by Robertson, and many new applications of color and design have since been created by the Company.

There has never been any publicity of this record while it was in the making, so it is told now to mark an important milestone in the history of the Company—not with any intention of boastful pride but rather with a deep sense of gratitude for the wise and prudent direction of Arthur D. Forst during the first forty years of the Company's life and with an added sense of responsibility in carrying on such a fine tradition of progress in the field of tile manufacture.

# ACTIVITIES OF THE SOCIETY

## NEW MEMBERS FOR OCTOBER

**Corporation**

FRENCH SAXON CHINA CO., W. V. Oliver (voter), Sebring, Ohio.

OWENS-CORNING FIBERGLAS CORP., F. V. Tooley (voter), Newark, Ohio (formerly in name of F. V. Tooley, personal member).

**Personal**

ASPER, D. C., Aspers, Adams County, Pa.; president, Penn Tile Works Co.

*BERRY, C. W., 104 Aberdeen Place, Clayton, Mo.; Research Dept., Laclede-Christy Clay Products Co.

BRUNT, ALBERT E., 407 Jackson St., Minerva, Ohio.

CASEY, JOHN F., Box 1888, Pittsburgh, Pa.; New Castle Refractories Co.

FRAZIER, CHAUNCEY T., 527 E. Beau St., Washington, Pa.; sales manager, Frazier-Simplex, Inc.

GLADDING, CHARLES, Third & Keyes Sts., San Jose, Calif.; president, Gladding Brothers Mfg. Co.

GRIFFITH, A. P., Emsco Refractories Co., South Gate, Calif.

HANES, JOHN G., 1416 Mahoning Ave., N. W., Warren, Ohio; superintendent, Masonry and Labor Dept., Republic Steel Corp.

*HOEHN, CHARLES J. P., 18th & Florida Sts., San Francisco, Calif.; president, Enterprise Engine & Foundry Co.

HOLLIES, SIDNEY R., 1017 Lawrence Rd., Trenton, N. J.; vice-president, Crescent Tile Co.

JORDAN, JOHN W., Mellon Institute, Pittsburgh, Pa.; Industrial Research Fellow, National Lead Co.

KERR, VAUGHN W., 836 Duncan Ave., Washington, Pa.; Frazier-Simplex, Inc.

LUSTER, VAYLORD R., 464 Canton, Detroit, Mich.; ceramist, Detroit-Michigan Stove Co.

MANKER, WILLIAM, Padua Hills, Claremont, Calif.; instructor, Scripps College.

MCGILL, LINCOLN A., 625 Market St., San Francisco, Calif.; district sales manager, Harbison-Walker Refractories Co.

MEYER, URSULA, 260 Riverside Dr., New York, N. Y.; ceramist, General Ceramics Co.

NAGEL, ERIC W., 5661 Natural Bridge Ave., St. Louis, Mo.; production manager, Wrought Iron Range Co.

PERKINS, WALTER W., 217 Kearny St., Hartwell, Cincinnati, Ohio; assistant control engineer, Cambridge Tile Mfg. Co.

PLAGGE, VERNON L., 42 Chestnut St., East Orange, N. J.; ceramic engineer, Lamp Div., Westinghouse Electric & Mfg. Co.

PLOETZ, EDWIN C. H., Group No. 31, Coast Artillery School, Fort Monroe, Va.; first lieutenant, U. S. Army.

SLAYTER, GAMES, Owens-Corning Fiberglas Corp., Newark, Ohio; vice-president.

STEWART, JOHN A., 422 E. Chestnut, Washington, Pa.; glass color technologist, B. F. Drakenfeld & Co., Inc.

VEALE, JACK H., General Refractories Co., Baltimore, Md.; ceramic engineer.

**Student**

*University of Alabama:* ANDREW TENCZA.

*University of Illinois:* ROBERT L. GROVE.

*Iowa State College:* BERNARD C. SMITH.

*Missouri School of Mines and Metallurgy:* J. K. JOHNSTON, L. N. LARSON, and ROBERT A. SMITH.

*Pennsylvania State College:* WARREN R. BECK, HAROLD FREED, SAMUEL B. MEYER, JR., GEORGE C. MUNROE, PAUL H. REED, DOUGLAS E. ROUDABUSH, and HORACE K. SHOENBERGER.

*Virginia Polytechnic Institute:* ALFRED W. ALLEN, RALPH V. LAWRENCE, and RAYMOND C. WOMELDORPH.

* Indicates former member of The Society rejoining.

## MEMBERSHIP WORKERS' RECORD

**Corporation**

| | | | |
|---|---|---|---|
| R. E. Birch | 1 | Office | 1 |

**Personal**

| | | | |
|---|---|---|---|
| R. E. Birch | 11 | R. W. Rowland | 1 |
| J. E. Frazier | 2 | H. A. Smith | 1 |
| L. C. Hewitt | 1 | J. E. Stevens | 1 |
| F. A. Kirkpatrick | 1 | E. W. Tillotson | 1 |
| | Office 4 | | |

**Student**

| | | | |
|---|---|---|---|
| A. I. Andrews | 1 | P. G. Herold | 3 |
| R. E. Birch | 1 | T. N. McVay | 1 |
| E. C. Henry | 5 | N. W. Taylor | 2 |
| | J. W. Whittemore 3 | | |

**Grand Total 41**

## ROSTER CHANGES DURING OCTOBER*

DURBIN, EDMUND A., 266 E. Torrence Rd., Columbus, Ohio (Detroit, Mich.)

EMLEY, WILLIAM S., 49 Nichol Ave., New Brunswick, N. J. (New Castle, Pa.)

HURST, THOMAS L., 497 Rutland Ave., West Englewood, N. J. (Pittsburgh, Pa.)

KREIDL, EKKEHARD, 155 Waverly Place, New York, N. Y. (Cleveland, Ohio)

KREIDL, IGNAZ, 155 Waverly Place, New York, N. Y. (Cleveland, Ohio)

KREIDL, WERNER, 155 Waverly Place, New York, N. Y. (Cleveland, Ohio)

LAIRD, STANLEY M., 1462 Guy St., Montreal, Quebec, Canada (Salem, N. J.)

MCCORMICK, JOHN M., 1345 Mohu Place, Honolulu, Hawaii (Butler, Pa.)

NICKS, JOHN F., Inuerary, Humberuiem Crescent, Weston, Ont., Canada (Grand Coulee, Sask., Canada)

THOMAS, S. L., JR., 7808 South Shore Dr., Chicago, Ill. (Westfield, N. J.)

WHITTINGTON, LLOYD R., 513 E. Robinson Ave., Barberton, Ohio (Fredericksburg, Ohio)

* Address in parentheses is former address.

# PLAQUE COMMEMORATING FOUNDING OF CERAMIC ENGINEERING EDUCATION

**Program for Unveiling of Plaque at Ohio State University, September 27**

*Chairman:* R. B. SOSMAN, U. S. Steel Corp., Kearny, N. J., Dean of Fellows of The American Ceramic Society.

(1) Presentation of plaque by ROSS C. PURDY, 2525 North High St., Columbus, Ohio, General Secretary of The Society.

(2) Acceptance of plaque by HOWARD L. BEVIS, president of Ohio State University, Columbus, Ohio.

(3) "Early History of the Department" by A. S. WATTS, chairman of the Department of Ceramic Engineering, Ohio State University.

(4) "Reminiscences of an Early Graduate" by L. E. BARRINGER, General Electric Co., Schenectady, N. Y., Trustee of the Edward Orton, Jr., Ceramic Foundation, Columbus, Ohio.

### Presentation of Plaque by Ross C. Purdy

On April 20, 1894, the Ohio Legislature passed a bill authorizing the Ohio State University to provide courses of study and laboratory practice in ceramic engineering. This bill did not have the approval of the University Trustees or of the Faculty. The legislators thought of it as a "mud-pie" enterprise, and those very words were written into the bill when it was first reported out by the committee. The bill was spoken of with disdain.

The promotor of this bill was a rugged individualist, Edward Orton, Jr., who was possessed with vision and determination and would not be daunted by ridicule or opposition.

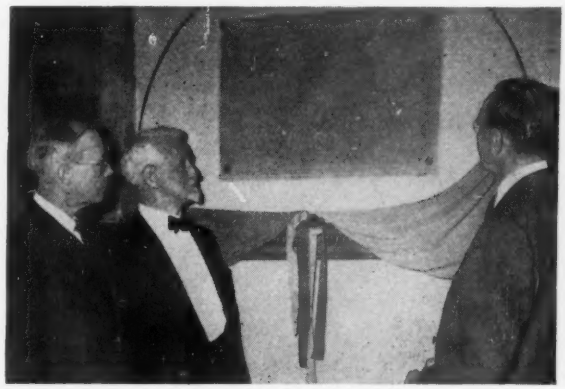
Edward Orton, Jr., had shown proficiency both in geology and in metallurgy. Personal reasons prompted him to abandon metallurgy for geology. It was in his economic geology studies that he found a branch of engineering that had not received attention—that of clay working. Geological reports on clays had been published by federal and state geological surveys, but they contained no practical applications of the recorded observations and data. Professor Orton decided to do something about it. He enlisted sufficient support of ceramic manufacturers to put the bill before and through the legislature. The Board of Trustees of the University gave him the responsibility of equipping the laboratories and formulating and directing the study courses.*

Twenty-five hundred dollars for equipment and expenses and twenty-five hundred dollars for salaries were appropriated by the legislature for the first year. The meagerness of this appropriation would have discouraged anyone less rugged than Edward Orton, Jr. Trusting his vision and ability, the clay workers donated most of the equipment and materials. Their trust was well placed.

* For Professor Orton's own story of the beginning and of the first class in the short or industrial courses, see *The Bulletin*, **19** [3] 107 (1940) (originally published in *Brick*, July, 1896).

Why should Edward Orton, Jr., repeatedly be given honor by ceramists? There are several substantial reasons, one of which is that in founding this Ceramic Department he did what no one else thought of doing.

But for his conceiving and establishing a collegiate Department of Ceramic Engineering, one probably would not have been established and The American Ceramic Society would not have been founded. The states of New York, New Jersey, Illinois, Iowa, Pennsylvania, Georgia, North Carolina, Alabama, Virginia, Missouri, Montana, and the provinces of Ontario and Saskatchewan probably would not have set up similar ceramic departments, and North Dakota, Washington, West Virginia, and Massachusetts probably would not have established degree courses in ceramics had not Edward Orton, Jr., founded this Ceramic Department in 1894 and The American Ceramic Society in 1898.



**Robert B. Sosman, Ross C. Purdy, and Howard L. Bevis viewing plaque which commemorates the founding of the Department of Ceramic Engineering at Ohio State University. A close-up view of the plaque is shown at the left.**

It is important to note that prior to the founding of this Ceramic Department and of The Society, the ceramic industries were becoming mechanized for mass production. Before this Ceramic Department was organized, the demands were pressing for better quality in ceramic ware of all kinds, and new products were being made. The increase in process mechanization and the increase in the number of new ceramic products prior to 1894 had resulted in the employment by the ceramic industries of college-trained engineers and scientists. The ceramic plants had already experienced considerable emergence from empirical to scientific production methods. Increase in transportation facilities had broadened the markets. Knowledge of compositions and of the art of producing ceramic ware was already being acquired by an increasing number of persons. This was the development trend at the time Edward Orton, Jr., founded this Ceramic Department.

Forty-seven years ago the instruction consisted largely of empirically proved knowledge. As scientific facts and methods were developed, ceramic instruction gradually progressed from the empirical to the scientific.

There is need today, as in 1894, for special collegiate instruction and training in ceramics. The Fellows of The American Ceramic Society recognize this fact, and for this reason present to Ohio State University this plaque which marks the time and place of the founding of the world's first collegiate ceramic school.

**Forty-Fourth Annual Meeting**
**Cincinnati, Ohio**
**April 19–25, 1942**

## HONORARY MEMBERSHIP

The Committee on Honorary Membership requests suggestions from members of The American Ceramic Society. If you have someone in mind who should be considered as an Honorary Member, send accurate information covering the following points to the Chairman of the Committee:

(1) Full name and address.
(2) Date and place of birth.
(3) Names of parents, with scientific and cultural background.
(4) Education, with institutions attended and degrees obtained (with dates).
(5) Positions held, with titles and dates.
(6) List of publications, with full titles and specific journal references.
(7) Membership in scientific societies.
(8) Honors received.
(9) Information concerning wife and children (if individual is married).
(10) Recent photograph of nominee.
(11) Your personal letter of recommendation.

The Committee on Honorary Membership is as follows:

ALEXANDER SILVERMAN, *Chairman;* Dept. of Chemistry, Univ. of Pittsburgh, Pittsburgh, Pa.
M. E. HOLMES: New York State College of Ceramics, Alfred, N. Y.
LOUIS NAVIAS: General Electric Co., Schenectady, N. Y.
G. A. BOLE: Eng. Expt. Sta., Ohio State Univ., Columbus, Ohio.

## OUR PRESIDENT INJURED

Jesse T. Littleton, president of The American Ceramic Society and assistant director of research at the Corning Glass Works, Corning, N. Y., and Mrs. Littleton are recovering from injuries sustained in an automobile accident near Bath, N. Y., on August 27. Mrs. Littleton is confined to their home at 31 East Fifth St., Corning, N. Y. Dr. Littleton returned to his office on November 4.

**Dr. and Mrs. Jesse T. Littleton as of October 19.**

**Dr. Littleton Appreciates Gift by Glass Division at Autumn Meeting**

"The one thing that makes the Glass Division such an interesting group is that it is not possible to prophesy just what the gang is about to do. One of the reasons that makes me glad that I am in the glass business is that there is such a nice bunch of fellows in it. Of course, there is nothing which can quite compensate for not being able to attend the meetings, but I wish to thank the gang for their thoughtfulness in remembering us so lavishly and it goes about as far as one could imagine in making up for the loss in attending the meeting. We have the electric blanket, radio, and bedside table. I don't know how anyone happened to think of such appropriate remembrances, but I am very sure that I could not have possibly thought of them myself." —J. T. LITTLETON

## REFRACTORIES DIVISION NOMINATIONS

The Nominating Committee for the Refractories Division reports the following nominations for Division officers for 1942–1943:

*Chairman:* R. S. BRADLEY, A. P. Green Fire Brick Co., Mexico, Mo.
*Vice-Chairman:* C. L. THOMPSON, Harbison-Walker Refractories Co., Pittsburgh, Pa.
*Secretary-Treasurer:* W. R. KERR, Armstrong Cork Co., Beaver Falls, Pa.
*Nominating Committee A:* GILBERT SOLÈR, Steel & Tube Div., Timken Roller Bearing Co., Canton, Ohio.
*Nominating Committee B:* C. A. FREEMAN, A. P. Green Fire Brick Co., Mexico, Mo.

# LOCAL SECTIONS

## MICHIGAN-NORTHWESTERN OHIO SECTION

The Michigan-Northwestern Ohio Section held a dinner meeting on October 17, 1941, at Devon Gables, south of Pontiac, Mich. E. A. McFaul, a well-known radio commentator, spoke on "So You Think You're Peculiar Too."

Later in the evening, the meeting was reconvened informally at nearby Kingsley Inn for a social hour.

—A. R. DECKER, *Secretary*

## PITTSBURGH SECTION

The Pittsburgh Section held its first meeting of the year on October 14 at Mellon Institute, Pittsburgh, Pa. Frank L. Jones, director of chemical research, Bausch & Lomb Optical Co., Rochester, N. Y., gave an illustrated lecture on "Optical Glass and National Defense." He compared the present optical glass situation in the United States with what it was at the beginning of the last World War and discussed methods of optical glass manufacture.

The second meeting of the Section was held on November 12 at Mellon Institute. Ralston Russell, Jr., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., spoke on "Recent Developments Related to High-Tension Electrical Porcelain." His talk was illustrated with motion pictures. —LOUIS A. SMITH, *Secretary*

## BALTIMORE-WASHINGTON SECTION

The first fall meeting of the Baltimore-Washington Section was held at the Longfellow Hotel, Baltimore, Md., October 25, 1941.

Following the dinner and business meeting, the Section was entertained by Jack Lambert, cartoonist of *The Baltimore Evening Sun*, who first models his cartoons in clay and then photographs them; the resulting photograph is the cartoon. Mr. Lambert gave a demonstration in modeling during his talk.

—W. R. LESTER, *Secretary-Treasurer*

# STUDENT BRANCHES

## VIRGINIA POLYTECHNIC INSTITUTE

The Student Branch of The American Ceramic Society at the Virginia Polytechnic Institute, Blacksburg, Va., held its first meeting of the school year on September 25, 1941.

The enrollment of ceramic engineering students increased 25% over that of last year with only a 10% increase in the student enrollment of the whole school. There are ten freshmen, ten sophomores, nine juniors, thirteen seniors, and two graduate students in the department; the faculty remains the same.

Program plans for the coming year include six motion pictures, two of which will be shown each quarter. Several lectures by industrial men and talks by members of the senior class are also planned.

After a short business session, the new members of the Student Branch were introduced and the meeting was recessed for an informal smoker.

—R. C. WOMELDORPH, *Corresponding Secretary*

## UNIVERSITY OF TORONTO

The attendance of first-year students in the Ceramic and Non-metallic Division of the Department of Metallurgy, University of Toronto, Toronto, Canada, shows an increase which is due largely to transfers from the overcrowded Department of Chemical Engineering. There are thirteen first-year students, three second-year, two third-year, and two fourth-year.

Certain changes have simplified the curriculum. More courses common to all are available to engineering students in the first two years; the wide diversity of selection, however, in the last two years is retained. The hours assigned to lectures and laboratories have been reduced from thirty-eight to thirty-three hours per week to allow students more time for library work and for personal study.

War needs enter into all of our plans. Many members of the staff are connected with some phase of war production and almost all of our graduates have enlisted or have entered war plants. The departments of Ceramics and Physics have aided greatly in the establishment, as a war measure, of the manufacture of optical glass in Canada.

These activities and the military studies required of undergraduates have interfered with college routine to some extent, but the interference is kept to a minimum so that our graduates will be adequately trained to take over the technical responsibilities they are expected to carry in our war effort.

—ROBERT J. MONTGOMERY,
*Associate Professor of Ceramics*

## NEW YORK STATE COLLEGE OF CERAMICS

The new school year is well under way with new equipment, an extended faculty, and a capacity enrollment. Senior thesis topics have been selected and actual work on them has been started.

At its initial meeting, the Student Branch laid the foundations for an active year under the leadership of George W. Kellogg, Royce D. Luce, Ralph Rhodes, Jr., and David L. Armant. Sixty dollars were set aside for new books for the rapidly expanding ceramic library.

Plans were made to have leading men of the ceramic industry talk at meetings of the Student Branch. The first guest speaker was F. W. Muller, manager of the High Temperature Div., Armstrong Cork Co., Lancaster, Pa., who spoke on "Insulation Refractories."

The staff of the *Alfred Engineer*, the newspaper of the Student Branch, headed by Kenneth R. Kleinman, Moe D. Cohen, David L. Armant, and Burton E. Baker, was organized and did splendid work in having the first edition ready for the eighth annual meeting of the Ceramic Association of New York held at Alfred on Friday, October 17. Members of Keramos also played a large part in helping to make the program of the Ceramic Association meeting run smoothly and efficiently.

The five following junior ceramic students have been selected as new Keramos members: Walter East, Elmo Fordham, Alan Lindquist, Jr., George Jones, and Raymond Iles.

—LAWRENCE BICKFORD

## GEORGIA SCHOOL OF TECHNOLOGY

The Student Branch of the Georgia School of Technology held an organization meeting on October 1 to elect the following officers for the coming year: A. B. Johnson, *President;* James Grodsky, *Vice-President;* James R. Allen, *Secretary;* and Charles Bryant, *Treasurer.*

New sophomores were invited to a welcome meeting and weiner roast on October 8. Lane Mitchell, new head of the Department, explained the objectives of the Student Branch and welcomed the new men. C. F. Wysong and Julian Harris also spoke. The meeting later adjourned to the kiln room where weiners were roasted over the frit furnace and cold drinks were served. The new men were inducted into the society the following week.

The first formal meeting was held on October 29. J. J. O'Shea, of the Buffalo Forge Co., Buffalo, N. Y., spoke on "Fan Installations in Ceramic Plants."

## UNIVERSITY OF NORTH CAROLINA

### October Meeting

The first meeting of the North Carolina Student Branch was held October 7, 1941, with the newly elected president, Charles D. Taylor, presiding.

After greetings and welcomes from A. F. Greaves-Walker and R. L. Stone, C. N. Kimball, R. B. Adair, and E. C. Hepler related their experiences on summer jobs with the Allied Engineering Company and the Mexico Refractories Company.

A committee composed of C. N. Kimball, *Chairman,* C. V. Rue, and J. E. Partlow was appointed by the president to make plans for the initiation of associate members into the Student Branch at the November meeting, at which time the annual Halloween Party will be held in the ceramic laboratory.

### Alumni News

Among the alumni visiting the department recently were Ensign Gus Palmer of the Navy Air Corps, who is stationed on the Aircraft Carrier "Wasp"; Lieutenant H. H. Thomas, Quartermasters' Corps attached to the First Army now on maneuvers; Lieutenant Martin Parcel, Quartermasters' Corps, stationed at Fort Bragg, N. C.; W. C. Cress, who is located at South Works, Carnegie-Illinois Steel Co., South Chicago, Ill.; and Addison Maupin, sales engineer for the General Refractories Co.

Ensign Stephen Derbyshire, who was serving in the Navy Department in Washington, has been returned temporarily to his position as assistant industrial hygienist in the North Carolina State Board of Health; Lieutenant R. P. McCabe has been ordered to the armored forces stationed at Fort Knox; and Lieutenant Frank P. Sabol, Air Corps, has been transferred from Chanute Field to Arizona.

A large percentage of the graduates of the department are reserve officers and are either now in the service or are awaiting orders to report.

### Keramos

The North Carolina Chapter of Keramos held its first meeting of the academic year on October 7. Several eligible juniors and seniors were nominated for membership and will be acted on at the November meeting.

### Project for Year

The principal project of the year will be the issuing of a bulletin on ceramic engineering which will be mailed to the high schools and junior colleges of North Carolina.

## UNIVERSITY OF ILLINOIS

**First Fall Meeting**

The University of Illinois Student Branch held an organization meeting on October 13. Professor Parmelee welcomed the new students and a tour of the Department was conducted.

**Other Activities**

The date for the annual Ceramic Ruckus, the only departmental dance on the campus and well known for its unique programs, has been set tentatively for December 6. The annual banquet, the Pig Roast, will be held some time in May. The *Illini Ceramist*, our newspaper, will be published again about the first of April.

**Officers and Committees**

Officers of the Student Branch for 1941–1942 are Robert L. Grove, *President;* Charles H. Salch, *Vice-President;* Vaughan F. Seitzinger, *Secretary;* and Earl R. Smith, *Treasurer.*

Chairmen of the Student Branch committees are as follows: Melvin Gibbs, *Ruckus Programs;* W. H. McLaughlin, *Membership;* M. N. Gruner and R. A. Giles, *Refreshments; Pig Roast and Athletics* (to be appointed). Richard Rowe is editor of the *Illini Ceramist* and Charles H. Salch is business manager.

—ROBERT L. GROVE, *President*

## SEVENTH CONFERENCE ON GLASS PROBLEMS

The Seventh Conference on Glass Problems was held at the University of Illinois, Urbana, Ill., on November 14 and 15, 1941, under the joint auspices of the Department of Ceramic Engineering at the University of Illinois and the Chicago Section of The American Ceramic Society.

The following program was presented:

(1) Progress report on research on molds for glass; research conducted by W. H. BRUCKNER, Dept. of Metallurgy, Univ. of Illinois.

(2) "Analysis of Strains in Glass Produced by Applied Ceramic Colors" by J. E. ABLARD, B. F. Drakenfeld & Co., Inc., Washington, Pa.

(3) "Elimination of Destructive Batch Dust in Continuous Tank Furnaces" by C. T. FRAZIER, Frazier-Simplex, Inc., Washington, Pa.

(4) "Some Aspects of Modern Furnace Design and Operation" by S. R. SCHOLES, N. Y. State College of Ceramics, Alfred, N. Y.

(5) "Recent Work on Cords in Glass" by W. B. SILVERMAN, Owens-Illinois Glass Co., Toledo, Ohio.

(6) "Sources of Stones in Glass" by D. W. ROSS, Kirkwood, Mo.

(7) "Research on Glass in Laboratories of the Department of Ceramic Engineering, University of Illinois" by C. W. PARMELEE and A. E. BADGER, Dept. of Ceramic Engineering, Univ. of Illinois.

A dinner was held on the evening of November 14 in the Illini Union Building. It was followed by an illustrated lecture, "Travels in Venezuela," by R. E. Crist of the Dept. of Geology and Geography.

# NECROLOGY

## HOMER N. BOOKER

Homer N. Booker, an engineer for the Federal Glass Co., Columbus, Ohio, died on October 2 after an extended illness.

Mr. Booker was born in North Star, Ohio, in 1901. He attended Ohio State University, where he received the degree of Bachelor of Science in Mechanical Engineering. He was employed by the Herman Manufacturing Company and the Anchor Hocking Glass Company before becoming associated with the Federal Glass Company.

Mr. Booker was a member of the Ohio Society of Mechanical Engineers and the American Society of Mechanical Engineers.

## HERMAN MUELLER

Herman Mueller, a Charter Member of this Society, died on September 22.

## GEORGE SIMCOE

George Simcoe, a Charter Fellow of The American Ceramic Society and director of research and assistant secretary of the Edgar Plastic Kaolin Co., Metuchen, N. J., died on October 14, 1941, while being operated on for appendicitis.

Mr. Simcoe was born in North East, Md., in 1878. He went to high school in Elkton, Md., and attended Ohio State University in 1899 and in 1902, where he took the short or industrial course which was given at that time.

From 1902 to 1923, he was associated with the following companies: 1902–1903, Cook Pottery Co., Trenton, N. J.; 1904–1909, Locke Insulator Co., Victor, N. Y.; 1910–1913, Electric Porcelain & Mfg. Co., Trenton, N. J.; 1914–1916, Otagon Insulator & Ceramic Co., North East, Md.; 1917, Empire China Co., Brooklyn, N. Y.; 1918, J. B. Owens Co., Metuchen, N. J.; 1919, M. D. Valentine & Brothers Co., Woodbridge, N. J.; 1920–1921, Electric Porcelain & Mfg. Co., Trenton, N. J.; 1922, Perth Amboy Tile Co., Perth Amboy, N. J. He had been with the Edgar Plastic Kaolin Company since 1923.

George Simcoe

**Ceramic Activities**

George Simcoe became a member of The American Ceramic Society in 1906 and was affiliated with the White Wares Division.

He was a leader in the Ceramic Association of New Jersey, having served in the several offices, including that of president; for several years he also served as a member of the executive committee.

He was a member of the ceramic group that toured Europe. He was a regular attendant of the Annual Meetings of The American Ceramic Society. Loyality, cordiality, and faithfulness to duties were characteristics of George Simcoe.

**Publications and Patents**

"Cost of Pottery Manufacture in the Green Room Stage," *Trans. Amer. Ceram. Soc.*, **8,** 108–11 (1906).

"Data on Plaster Molds," *ibid.*, **9,** 187–94 (1907).

"Life of a Sagger," *ibid.*, **11,** 216–27 (1909).

"Pug Mills," *ibid.*, pp. 343–53.

"Sagger Making," *ibid.*, **12,** 205–206 (1910).

"Pugging Clay," *ibid.*, pp. 376–82.

(With A. E. Smith), "Manufacture of Dust-Pressed Ware," *ibid.*, pp. 196–204.

(With A. E. Smith), "Oils, Fats, and Greases for Die Greasing in Manufacture of Dust-Pressed Ware," *ibid.*, **14,** 558–70 (1912).

"Importance of Sagger-Making Department," *ibid.*, **17,** 256–73 (1915).

"National Review of Sagger Situation," *Jour. Amer. Ceram. Soc.*, **4** [5] 393–406 (1921).

"Tubular Insulator," U. S. Pat., 1,072,999, Sept. 9, 1913.

"Refined Clay and Method of Production," U. S. Pat. 1,888,701, Nov. 22, 1932.

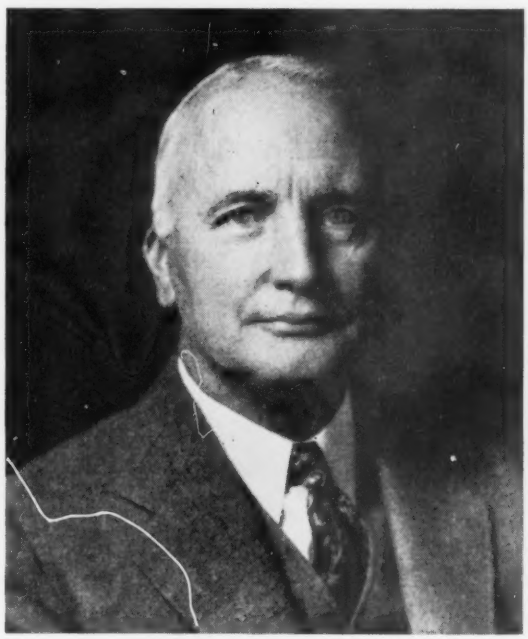
## HARRY SLOAN HOWER

Harry Sloan Hower, head of the Department of Physics at Carnegie Institute of Technology, died October 10, 1941, at Mercy Hospital, Pittsburgh, Pa., after an illness of three weeks.

Professor Hower, who was sixty-four years old, had served with the faculty of the Carnegie Institute of Technology since 1906. He had taught more Carnegie Tech men than any other member of the faculty (as all engineering students took his physics class) and he was one of the best-loved figures of the Institute.

Beyond his teaching duties, he was designer of lenses for range lights for the Panama Canal Commission, U. S. Navy submarines, U. S. Army searchlights, and the Norwegian merchant marine. He was also consultant for the Corning Glass Works. He is listed in Who's Who in America for his scientific and educational accomplishments.

A native of Parker, Pa., Professor Hower studied at the Case School of Applied Science and the University of Berlin. He served as instructor at the Case School before becoming associated with the Institute as professor of physics. He became head of the Department of Physics in 1915.



Harry S. Hower

He was a fellow of the American Physical Society and of the American Association for the Advancement of Science and a member of the American Optical Society, Society for the Promotion of Engineering Education, Illuminating Engineering Society, Society of Glass Technology (English), Pennsylvania Academy of Science, Sigma Xi, and Tau Beta Pi. He had been a member of The American Ceramic Society since 1918.

Professor Hower is survived by his widow, a daughter, and three sons, Thomas Chester, Shell Oil Co., Wichita Falls, Tex.; Harry Sloan, Corning Glass Works, Corning, N. Y.; and William Henry, II, Douglas Aircraft Co., Inc., Santa Monica, Calif.

President Robert E. Doherty of the Carnegie Institute of Technology paid the following tribute to Professor Hower: "Through the death of H. S. Hower, head of the Department of Physics, the Carnegie Institute of Technology has lost one of its distinguished teachers. In 1906, one year after the opening of the Institute, he became a member of the faculty and from that time on has given unsparingly of his loyal and efficient services. Because of his human interest, his sincere consideration, and his kindly disposition, he was known as 'Happy' Hower. He typified the ideal professor and administrator.

"Off the campus, Professor Hower gained equal recognition. He was distinguished also as a technical expert and made outstanding scientific contributions in the field of glass and optics.

"The faculty, students, and alumni will miss his kindly counsel, his wise and inspiring leadership, and the example he has set throughout thirty-five years of our institution's history."

## ARTHUR TELFER FALCONER

Arthur T. Falconer, treasurer and general manager of the Mosaic Tile Company, Zanesville, Ohio, died on September 25 after an illness of several months. He was fifty-seven years old.

Mr. Falconer was born on March 27, 1884, in Toronto, Ohio. After working as advertising manager for several newspapers in East Liverpool, Ohio, he served as a bank and building and loan examiner for the State of Ohio. In 1919, he moved to Twinsburgh, Ohio, where he was

Arthur T. Falconer

cashier for the Twinsburgh Bank. In 1921, he became a stock and bond salesman for the Richard, Parish, and Lamson Brokerage Company in Zanesville.

In October, 1923, Mr. Falconer joined the Mosaic Tile Company as an auditor, serving in that capacity until 1926, when he became treasurer of the Company and a member of the Board of Directors. He was named general manager in 1936.

Mr. Falconer was the voting representative of the Mosaic Tile Company, which has been a Corporation Member of The American Ceramic Society since 1917.

## PERRY A. SMITH

Perry A. Smith, manufacturer and civic leader, died at his home in New Brighton, Pa., on June 23, 1941. He was seventy-four years old.

He was born in Fallston, Pa., on February 24, 1867, and spent his entire life in that area. At the time of his death, he was president and treasurer of the A. F. Smith Co., a company established by his father in the early eighties.

Mr. Smith contributed a full life to civic, charitable, church, and other community affairs. He served on the Boards of Directors of the Beaver Valley General Hospital, the Providence Hospital, and the Beaver County Red Cross. He was also at different times school director, supervisor, justice of the peace, and township treasurer in his home district.

Several years ago, he was awarded the honorary life degree in the Knights of Columbus.

Mr. Smith is survived by his widow, three sons, and four daughters. One of his sons, Louis A., of the Jones & Laughlin Steel Corp., Aliquippa, Pa., is an active member of The American Ceramic Society. Mr. Smith himself was a member of The Society from 1906 to 1937.

## FREDERICK STANGER

Frederick Stanger, president of the Enterprise White Clay Co., Philadelphia, Pa., died on September 15 at the age of fifty-four.

He was widely known throughout the ceramic industry in the eastern district and had founded the Company of which he was president a number of years ago to deal in domestic and imported clays. For some time before the War, his Company engaged largely in the distribution of German clays.

Mr. Stanger had been a member of The American Ceramic Society since 1915. He was also a member of the Ceramic Association of New Jersey, where he had served for many years as a member of the executive committee.

## DAVID W. SCAMMELL, JR.

David William Scammell, Jr., production manager of the Scammell China Co., Trenton, N. J., died October 1, 1941, at the St. Francis Hospital in Trenton following a long heart illness. He was thirty-two years old.

Mr. Scammell was born at Titusville, N. J., and attended Lawrenceville School and Norwich University. He became associated with the Scammell China Company following his graduation from Norwich University in 1932.

## ADDITIONAL NOTES ON J. F. KREHBIEL*

By Paul E. Cox

"Krebe" worked his way through college as a combination janitor, mechanician, and, without official appointment, as a part-time teacher. He lived in a room in the attic of the building now known as Binns Hall. He was the official photographer for the pictures used by Charles Fergus Binns in his needed publicity for the newly established School of Ceramics. When the blueprints for the many construction jobs appeared, it was usually Krehbiel who had made the drawings and prints. The testing of clays for structural clay products, which did not demand extensive ceramic knowledge, usually was done by Krehbiel, for Professor Binns had to handle the laboratories which dealt with fine ware. All of the production of fired samples of brick and tile was done by Krehbiel. Millwrighting, kiln firing, clay testing, photography, janitoring, and maintenance were the tasks Krehbiel had while earning the first degree in ceramics from the New York State School of Clay Working and Ceramics.

Krehbiel taught woodworking during the absence of Lynn Crandall, who was away for some weeks because of the death of his mother. If he had not been more sympathetic toward the football players than Crandall, I would never have been able to make up my laboratory time in the woodshop. Krehbiel permitted me to double up and get the exercises finished.

Alfred University had a number of men doing instruction work while working toward degrees. All of them were exceptionally skilled men who combined interest in the mathematical sciences with exactness in the crafts. Krehbiel was, therefore, generally using any small leisure he had in the company of this group.

Owing to the limited budgets of those early days of the history of Alfred's great College of Ceramics, Krehbiel's contribution to the start of the work should be regarded as equivalent to that of a junior staff member with faculty standing.

His undergraduate thesis resulted in the development of an elutriation apparatus which is always mentioned when the greatest of scientists write about methods of clay testing. A. B. Searle, an English authority, in his book entitled the Chemistry and Physics of Clays and Other Ceramic Materials, page 52, comments on the elutriating apparatus as follows: "By this means a good separation can be effected, though a long time and a very large volume of water are required." This one sentence is a concise statement of the working methods of Krehbiel. His first interest was always in a satisfactory product or result and the time used was of no consequence to him.

He was a user of tools. Mathematics to him was a tool. A saw, hammer, balance, voltmeter, or a mathematical science were tools to be used to make a device or product as nearly perfect as he could make such things.

It came as a surprise to me that Krehbiel had gone far in Masonry and in church work. Contacts of this sort had not seemed important to Krehbiel when he was younger; life, therefore, had ripened him.

Krehbiel had an exceptionally large collection of precision information on ceramics. It was characteristic of him to have such information in careful note form and to make no steps without a study of the notes. And it was also characteristic of him to seek the cheapest possible method for doing any bit of work, even at the expense of his personal leisure and comfort.

The one hobby he indulged in was that of photography. He came to New Orleans to the Annual Meeting of The American Ceramic Society loaded down with cameras and adjuncts; his sister even carried a few additional pieces. When he called on me at the small pottery plant where I was working, his time was divided between friendly chats about old times and the fine goats owned by a breeder nearby. Krehbiel knew goat breeding as well as he did cone making or ceramic products testing.

Krehbiel and Binns did not exactly mesh. Binns could not understand a man who did not enjoy working in fine ceramics, and Krehbiel did not understand a man who did not prefer to be an engineer above all other things. And so Krehbiel talked all of his life about the differences of opinion and, whenever opportunity offered, tried his hand at making the fine articles in fine bodies, just as Binns wanted him to do. Binns certainly was keenly interested in the elutriation apparatus; he probably suggested the thesis subject.

It was a good thing for the early graduates of Alfred's School of Ceramics that Krehbiel was around to tuck in the mechanical ends. He did a lot more toward making the place shipshape than he had to do under his bargain, and I have no recollection of ever hearing him whine about having to do the work.

He was of the lyceum days of Alfred, and those days resulted in a few high-grade scholars. I think Krehbiel was one who got all that the lyceums could supply.

* A notice of Mr. Krehbiel's death, including a biographical sketch, was published in the September, 1941, *Bulletin*, p. 323. Additional material about the character, qualities, and ceramic contributions of Mr. Krehbiel has been gathered by Dr. Cox, New Orleans, La., a fellow student. The material was forwarded to the *Bulletin* Editor by J. Nelson Norwood.

# PERSONAL NOTES

## WILLIAM S. EMLEY

William S. Emley, former technical director of the New Castle Refractories Co., New Castle, Pa., has joined the faculty of the Ceramics Department of Rutgers University, New Brunswick, N. J.

Following his graduation from Rutgers in 1928, Mr. Emley taught ceramics at New Castle for several years under the School of Mineral Industries Extension Division of the Pennsylvania State College; more recently he has conducted classes for Engineering Defense Training as part of the national program of the United States Office of Education.

Mr. Emley has been a member of The American Ceramic Society since 1928.

## J. J. CANFIELD PERFECTS WEIGHT CALCULATOR

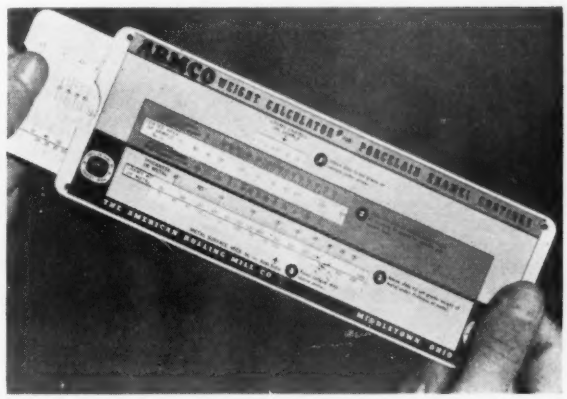
J. J. Canfield, who has perfected the new weight calculator for porcelain enamel coatings, is well known among enamelers through his close association with the industry.

J. J. Canfield

As a member of the American Rolling Mill Company Research Laboratories staff since 1928, he has specialized in the enamel and enameling iron research fields.

Dr. Canfield was born in Jennings, Okla. He received his Bachelor of Arts degree in 1916 from Oklahoma A. and M. College and earned his Master of Science and Doctor of Philosophy degrees while teaching chemistry at Iowa State College. After obtaining his Doctor's degree in 1926, he worked in the Oklahoma oil fields for two years before becoming associated with the American Rolling Mill Company.

He is a member of the American Chemical Society, The American Ceramic Society, Sigma Xi, Phi Lambda Upsilon, and Phi Kappa Phi.




Armco Weight Calculator

## CHARLES J. PHILLIPS

**Author of Book on Glass**

Charles J. Phillips, sales manager of the Insulation Division of the Corning Glass Works, Corning, N. Y., is the author of a book entitled Glass, the Miracle Maker, which was published by the Pitman Publishing Corporation in September, 1941. An abstract of the book will be published in the January, 1942, issue of *Ceramic Abstracts*.

Mr. Phillips received the B.S. degree in Physics from the University of Pittsburgh, Pittsburgh, Pa., and the M.A. degree in Physics from Oberlin College, Oberlin, Ohio.

From 1927 to 1930, he was employed as a research assistant at the Mellon Institute of Industrial Research, Pittsburgh, Pa. In 1931, he became associated with the Corning Glass Works as a physicist in the Physical Laboratory. He has been in the Insulation Division since 1937.

**Other Publications**

"Electron Diffraction for Classroom Demonstration," *Physics*, p. 48 (Jan., 1932).

"Electronic Diffraction," *Electronics*, p. 84 March, 1932).

"Electric Range Oven Performance," *Elec. World*, p. 527 (Oct. 15, 1932).

"Stresses in Curved Disks," *Product Eng.*, p. 231 (June, 1933).

"Reflectivity of Enameled Steel," *ibid.*, p. 310 (Aug., 1933).

(With M. L. Nordberg), "Ovenware and Fuel Economy," *Jour. Home Econ.*, p. 37 (Jan., 1934).

"Diffraction of Electrons," *Electronics*, p. 290 (Sept., 1935).

"Raman Spectra and the Latent Heat of Fusion of Nonassociated Substances," *Indian Jour. Phys.*, p. 447 (Dec., 1936).

C. J. Phillips

"Glass as an Electrical Insulator," *Jour. Applied Phys.*, p. 173 (March, 1940).

"Introduction to Chemistry of Glass," *Can. Chem. Process Ind.*, p. 33 (Jan., 1941).

## MARY E. COOK MODELS BUST OF EDWARD ORTON, JR.

From memory aided by photographs, Mary E. Cook, Columbus, Ohio, made a bust of Edward Orton, Jr., for placement in the lobby of the laboratories of the Edward Orton, Jr., Ceramic Foundation in Columbus.

A plaster mold was made by Miss Cook and the bust was hand-pressed by Edgar Littlefield and stained and fired by him in the laboratories of the Ceramic Art Department of Ohio State University.

The bust is stained black to match a bust of Josiah Wedgwood. The two busts are placed in niches on opposite walls of the lobby of the Foundation.

Bust of Edward Orton, Jr., modeled by Mary E. Cook

***He Succeeds Who Determines So to Do***

# NOTES AND NEWS

## CERAMIC ASSOCIATION OF NEW JERSEY

The Ceramic Association of New Jersey held its autumn meeting at the Department of Ceramics, Rutgers Univ., New Brunswick, N. J., on October 18. An interesting program was arranged for the day.

## CERAMICS AT BATTELLE

Charles F. Lumm has joined the technical staff of Battelle Memorial Institute, Columbus, Ohio, and he has been assigned to the division of ceramic research.

Mr. Lumm was graduated from Purdue University with a degree in chemical engineering, and he was associated with the Byerlyte Corp., Newark, Ohio, before joining the Battelle staff.

## UNITED STATES POTTERS ASSOCIATION

The Sixty-Third Annual Meeting of the United States Potters Association will be held at the Hotel Hollenden, Cleveland, Ohio, on December 9 and 10, 1941. A dinner will be held on Tuesday night, December 9; all persons wishing to attend are urged to send in their reservations as early as possible.

## AVAILABLE RESEARCH FELLOWSHIP AWARDS

Nine leaders in scientific research have been named to nominate the recipient and administer one Fellowship each in the Sixth Annual Series of Fellowship Awards of the Lalor Foundation.

The scientists named are as follows: Detlev W. Bronk, professor of biophysics and director of the Johnson Foundation, Univ. of Pennsylvania, Philadelphia, Pa.; E. J. Cohn, professor of biochemistry, Harvard Medical School, Boston, Mass.; Edward A. Doisy, director, Dept. of Biochemistry, St. Louis Univ. School of Medicine, St. Louis, Mo.; W. F. Giauque, professor of physical chemistry, Univ. of California, Berkeley, Calif.; A. Baird Hastings, Hamilton Kuhn professor of physiological chemistry, Harvard Medical School, Boston, Mass.; Carl S. Marvel, professor of organic chemistry, Univ. of Illinois, Urbana, Ill; Harold C. Urey, professor of chemistry, Columbia Univ., New York, N. Y.; H. B. Vickery, biochemist-in-charge, Biochemical Lab., Connecticut Agricultural Experiment Station, New Haven, Conn.; and Roger J. Williams, professor of chemistry, Univ. of Texas, Austin, Tex.

The Fellowship Awards, for the academic year 1942–1943, carry a stipend of $2000 each. The degree of Doctor of Philosophy or the equivalent is the minimum requirement for candidacy. The Awards are open to both men and women residents of the United States and Canada.

Candidates will be rated on their demonstrated ability, training, and work accomplished to date. Application forms and further particulars may be obtained by addressing any of the administrators direct or by writing to C. Lalor Burdick, director, the Lalor Foundation, Lancaster Pike and Baltimore Rd., Wilmington, Del. Applications should be filed before December 31, 1941, and appointments will be announced early in 1942.

The Awards of the Lalor Foundation are intended for the support of purely scientific research. Appointees to the current 1941–1942 Series of Fellowships are now conducting research at Johns Hopkins University Medical School, Harvard University, Columbia University, and the University of Illinois.

Since the organization of the Foundation in 1935, thirty men and women have completed Fellowships under the Foundation.

## ROOKWOOD POTTERY SOLD

Walter E. Schott, a Cincinnati automobile dealer, was the successful bidder for the Rookwood Pottery which was sold for $60,500 at a bankruptcy auction on September 29, 1941.

The Pottery will be operated "on the same high plane as in the past and with adequate capital to enable it to regain its former enviable position."

Associated with Mr. Schott in the venture are his wife, Mrs. Margaret C. Schott, who has been interested in the affairs of the Pottery for many years; his brother, Harold C. Schott; Charles M. Williams, vice-president of the Western and Southern Life Insurance Co.; and Lawrence H. Kyte, the attorney who made the successful bid.

John D. Wareham, long associated with the Pottery, will continue as director. He will have his old staff with him, including Ralph G. Leeds.

Elizabeth Lincoln, E. T. Hurley, Sara Sax, Lorinda Epply, K. Shirayamadani, and Mr. Wareham will form the nucleus of the new decorating staff.

Since the Pottery was founded more than six decades ago by Mrs. Maria Longworth Storer (who named it Rookwood for her father's country estate near Cincinnati), it has played an important part in identifying Cincinnati as a center of art in the museums and art centers of the world. (For a history of Rookwood Pottery, see *Bull. Amer. Ceram. Soc.*, **15** [12] 443–45 (1936).)

Three years after Mrs. Storer founded the Pottery, W. W. Taylor became her partner and active director of the Pottery. He remained the controlling influence in the Pottery until his death in 1913; his stock was then placed by will in the hands of trustees for the perpetuation of the policy which had given Rookwood its unusual character as an art industry. It was also under the direction of Mr. Taylor as president that the present buildings of the Pottery were erected in 1892 on the summit of Mount Adams.

Clays used for all purposes in the Pottery are entirely American and come mostly from the Ohio Valley. The Pottery has been managed on lines opposite to the prevailing factory system, for an effort has been made to attain a higher art rather than a commercial output. No printing patterns are used and no duplicates are made of signed, decorated pieces.

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## CONTEMPORARY CERAMICS AT SYRACUSE MUSEUM OF FINE ARTS

### Tenth Anniversary of National Ceramic Exhibition

Ceramic ware representing more than two hundred artists in the United States and artists in fifteen South and Central American countries, Canada, and Iceland has been assembled in the first Exhibition of Contemporary Ceramics of the Western Hemisphere, organized in celebration of the tenth anniversary of the National Ceramic Exhibition and sponsored jointly by the Syracuse Museum of Fine Arts, Syracuse, N. Y., and the International Business Machines Corporation.

The following countries are represented in the Western Hemisphere Exhibition: Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Cuba, Ecuador, El Salvador, Iceland, Mexico, Panama, Paraguay, Puerto Rico, the United States, Uruguay, and Venezuela.

Prizes for work of United States artists selected by a jury representing several important aspects of the ceramic field (members of the jury were listed on p. 372, October, 1941, *Bulletin*) were announced at the preview at the Syracuse Museum on October 18 by Miss Anna Wetherill Olmsted, director of the Museum and in 1932 founder of the National Ceramic Exhibition as a memorial to the late Adelaide Alsop Robineau, famous ceramist of Syracuse. South American and Canadian work was not subject to the jury; it was purchased for the Exhibition by Thomas J. Watson, president of the International Business Machines Corporation because of his interest in contemporary art and his efforts to help in the development of a more thorough understanding between the American continents.

### PRIZE AWARDS

#### Enamels

(1) KARL DRERUP, Rockville Center, Long Island, N. Y.: Three bowls, (1) still life in red, enamel on copper, (2) blue fish, enamel on copper, (3) cows, enamel on copper; and "Enchanted Garden" from a mural for a nursery room, enamel on copper ($200 prize from International Business Machines Corp., New York, N. Y.).

(2) MRS. RUTH RAEMISCH, Providence, R. I.: "Mexican Ranch," enamel; "Two Women with a Child," cloisonné enamel; "Soldier and His Horse," enamel; and "Girl with Flower," grisaille technique ($50 prize from B. F. Drakenfeld & Co., Inc., New York, N. Y.).

#### Sculpture

(1) BERNARD E. FRAZIER, Lawrence, Kans.: "Prairie Combat, Battle of Two Buffalo Bulls," stoneware with glaze of native volcanic ash, a product of original research ($100 prize from Harshaw Chemical Co., Cleveland, Ohio).

(2) W. W. SWALLOW, Allentown, Pa.: Pennsylvania Dutch groups: "Amish Bride and Groom, the Bishop and the Dowry," unglazed terra cotta; "The Amish Way," red terra-cotta wall tile ($100 prize from Hanovia Chemical Mfg. Co., Newark, N. J.).

(3) LYMAN S. CARPENTER, Chicago, Ill.: "Mother and Kid," yellow mat glaze ($50 prize, a Katherine Q. Payne Memorial Award).

(4) VALLY WIESELTHIER, New York, N. Y.: "Taming the Unicorn," glazed figure ($50 prize, half of $100 prize from Commercial Decal, Inc., East Liverpool, Ohio).

#### Pottery

(1) EDWIN AND MARY SCHEIER, Durham, N. H.: Five small bowls, decorated stoneware; vases, striped stoneware, and incised decoration on stoneware; bowls, incised stoneware, and applied decoration on stoneware ($100 prize from Onondaga Pottery Co., Syracuse, N. Y.).

(2) DON SCHRECKENGOST, Alfred, N. Y.: Punch bowl ($100 prize from United States Potters Association, East Liverpool, Ohio).

(3) GERTRUD AND OTTO NATZLER, Los Angeles, Calif.: Bowl, patina glaze; plate, white-brown ornamental glaze; two flower containers, velvet chartreuse glaze ($100 prize from Ferro Enamel Corp., Cleveland, Ohio).

(4) EDGAR LITTLEFIELD, Ohio State Univ., Columbus, Ohio: Gray vase, earthenware ($50 prize from Iroquois China Co., Syracuse, N. Y.).

(5) THOMAS S. HAILE, Alfred, N. Y.: "Orpheus," stoneware pot fired in reducing atmosphere ($50 prize from Pass & Seymour, Inc., Syracuse, N. Y.).

(6) CRUCITA T. CRUZ, Pueblo Indian Arts and Crafts, Albuquerque, N. Mex.: Decorated plate ($50 prize, half of $100 prize from Commercial Decal, Inc., East Liverpool, Ohio).

## CANADIAN POTTERY

The work of twenty-six Canadian potters was selected by Miss Olmsted from a special exhibition arranged by the Canadian Potters' Guild at the Toronto Exposition last summer. The list of Canadian potters is as follows: Mrs. Marguerite C. Baines, Eugenia Berlin, Mrs. John Bennett, Molly Carter, Mrs. R. M. Carthy, Norah Cooper, Mrs. Nancy Dawes, Kjeld Deichmann, Mrs. Donald Galt, Mrs. Illy Gepe, Prudence Dawes Gilmore, Ivy Hamblett, Mrs. Bailey Leslie, Mrs. Luke Lindoe, Margaret Lytler, Mary McPherson, Gladys Montgomery, Mr. Cameron Paulin, Mrs. May Rowlands, Mary Satterly, Jacques Spinard, Mrs. H. F. C. Stikeman, Kathleen M. Towers, Mrs. Dora Weschler, Dorothy Wilson, and Nunzia d'Angelo Zavi.

# COORDINATION BETWEEN INDUSTRIES IN INDUSTRIAL RESEARCH*

By C. G. Worthington†

**ABSTRACT**

This is a survey of the present cooperation between companies as to (1) joint activities in research, (2) the exchange of information, and (3) the publication of research findings. It is based on the activities of companies which represent many of the industries and industrial areas of the country.

Joint research carried on by industrial companies takes the form of (*a*) cooperation in the research activities of technical societies and trade associations, (*b*) cooperation with other companies in the development of a new product, a new process, or a new raw material which all the companies are interested in commercializing, and (*c*) cooperation in financing industrial research in universities and in government research foundation and private consulting laboratories.

Research information is exchanged among industrial concerns through members of their staffs participating in the meetings and serving on the committees of technical societies and trade associations. The general policy is to encourage the publication of research findings which contribute to technical knowledge unless such a step would jeopardize a company's position or reveal proprietary secrets. Information about the organization, management, and administration of research in industry is exchanged at group meetings of industrial executives and of research directors.

## (1) Joint Activities in Research

Scientific and engineering societies and trade associations conduct many investigations which are so broad in scope and so general in interest that no one company would be justified in making the necessary expenditures for them. A number of interested concerns, however, will cooperate as a group in financing and supervising such investigations. They are generally conducted in university, government, or private laboratories and are usually concerned with (1) obtaining fundamental scientific and engineering data, (2) the development of test procedures and analytical methods, and (3) to some extent with finding new applications for raw materials.

Several companies may also engage in a cooperative research program directed toward the development of a new product, a new process, or a raw material. Most of the joint activities of this nature are carried on by a company and its customers or its suppliers of raw materials and equipment. This is a logical activity, as each concern stands to profit from the successful commercial utilization of the new product, process, or raw material. Such cooperation is quite general among industrial concerns, though it does not often represent a large part of their research activities. It is distinct from sales service or trouble shooting.

Within the past few years, there have been many notable examples of products developed as the result of the joint research efforts of a number of companies. Among these are (1) the sealed beam headlight for automobiles, in the development and production of which a nationally known electrical manufacturing company joined with equally well-known glass, rubber, and other companies, and (2) the bullet-resisting tire, recently announced by the Ordnance Department of the United States Army, which has been a cooperative development of such major rubber companies as Firestone, Goodrich, Seiberling, Goodyear, and United States Rubber.

Many companies which carry on research cooperate with universities. Such cooperation generally involves either (1) fundamental scientific studies in the general fields of the company's interests, or (2) specific investigations with definite objectives and of a nature directly related to the operations of the company. The industrial concern usually provides only the funds for the work and the university provides the research facilities, personnel, and supervision. Fundamental scientific studies are generally set up as fellowships for students working for advanced degrees. Specific investigations usually require full-time trained personnel and administration with frequent reports to and conferences with the industrial sponsor. A number of companies in addition employ faculty members as consultants.

Industry also supports research programs in private consulting and industrial research foundation laboratories. These projects are generally of a specific, confidential nature with a definite commercial objective requiring energetic attack and early solution of the problem. Such laboratories as the Mellon Institute for Industrial Research, Battelle Memorial Institute, and Arthur D. Little, Inc., are typical of such agencies.

There is some small degree of cooperation in research between industrial concerns and governmental laboratories. The projects are usually of general scientific nature and are of interest to a number of companies, all of whom contribute to their support. In the field of agriculture, some national and state experiment stations cooperate directly with one or more companies in the development and testing of new raw materials or of industrial products that may have applications in agriculture.

Some companies spend as much as 10% of their research budgets on cooperative research programs with university, private, and government laboratories. The usual figure, however, seems to be nearer 2 to 3%. There is an occasional exchange of personnel on projects and of course considerable exchange of information in the form of conferences and reports.

## (2) Exchange of Information

The most general means of exchanging research information among industrial concerns is through participation in the meetings and technical committee work of technical societies and trade associations.

Many members of the industrial research staffs belong to technical societies and present their findings of technical value at the meetings of such societies.

These societies and associations also sponsor a great deal of committee activity which benefits industry as well as the technical professions and the public. This work is directed toward the formulation of industrial standards and specifications, testing procedures, analytical methods, and related subjects. New scientific and engineering data are also obtained through their cooperative research programs. Industrial organizations are well represented in the membership of these committees, contributing the time and expenses of their representatives as well as much of the information needed.

## (3) Policies on Publication of Research Findings

The general policy of enlightened companies seems to be to encourage their staffs to publish research findings when (1) these results are of broad interest and represent real contributions to technical knowledge, and when (2) such publication does not jeopardize the company's patent position or reveal proprietary secrets. Many research results appear first in patents and are later generalized either in articles in the technical press or in papers presented before technical societies.

Technical items of current interest are also published in some ninety industrial research laboratory house organs as listed in the National Research Council's Bulletin No. 102 entitled "Industrial Research Laboratories of the United States."

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* From Research, A National Resource, a report of the National Research Council to the National Resources Planning Board; 370 pp. For sale by the Superintendent of Documents, Washington, D. C.; price $1.00.

† Secretary, Industrial Research Institute, Chicago, Ill.

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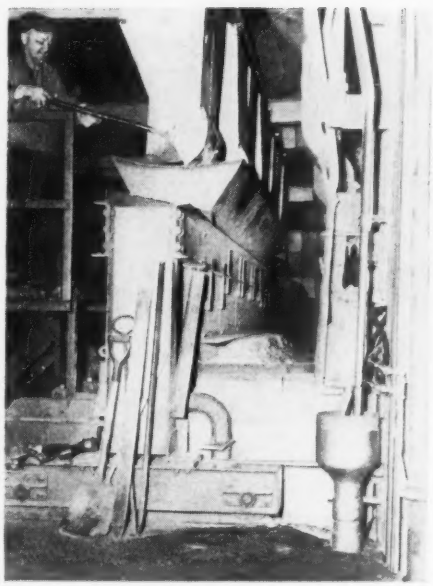

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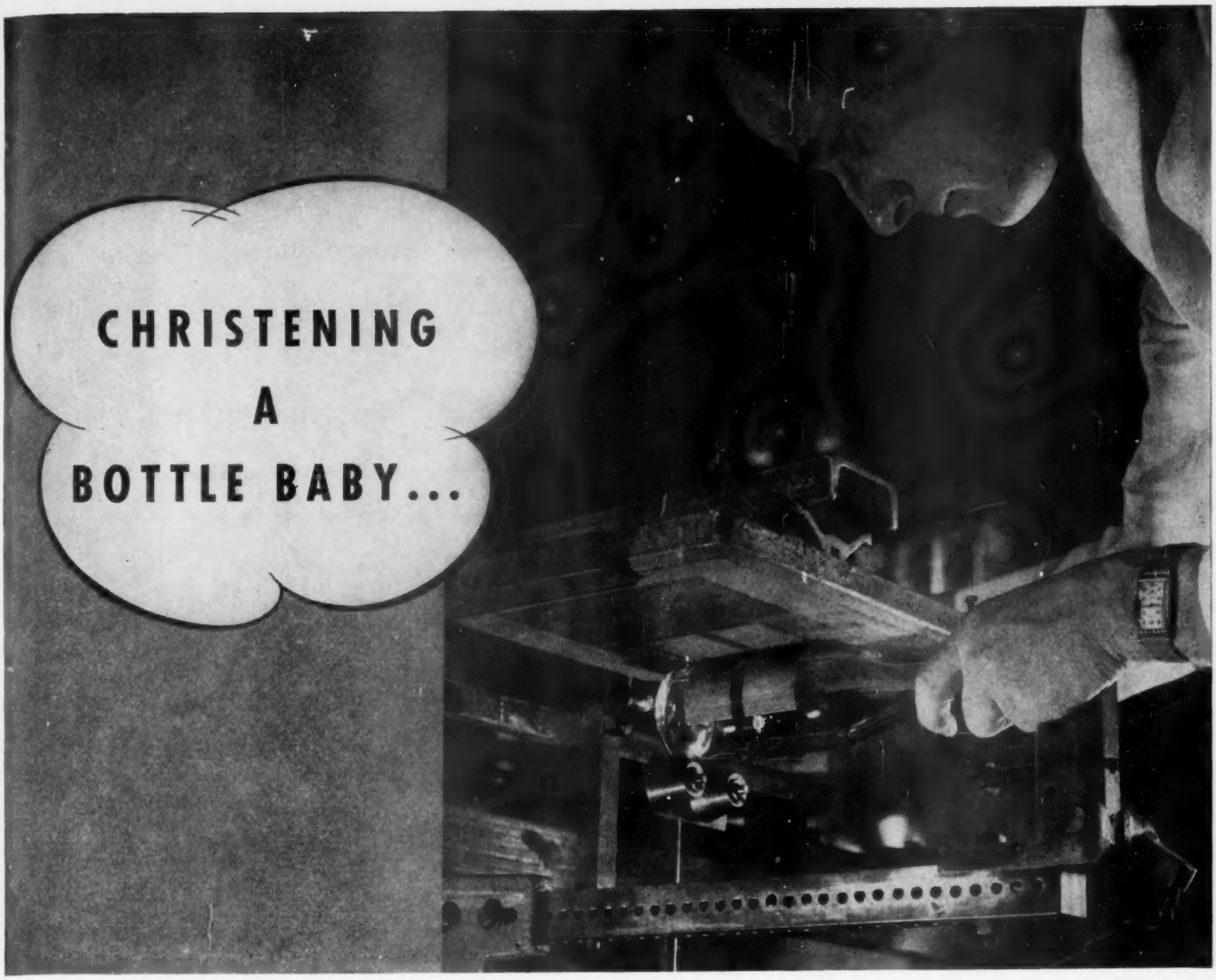


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Corhart Refractories Co.

**Enamelers' Borax**
Porcelain Enamel and Mfg. Co.

**Enameling Equipment (Complete)**
Ceramic Color & Chemical Mfg. Co.
Frazier-Simplex, Inc.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
The Vitro Mfg. Co.

**Enameling Furnaces**
Carborundum Co.
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Lancaster Iron Works, Inc.
Norton Co.

**Enameling Iron (Sheet)**
American Rolling Mill Co.

**Enameling Muffles**
Carborundum Co. (*Carbofrax*)
Frazier-Simplex, Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Norton Co. (*Alundum*)

**Enameling (Practical Service)**
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Metal & Thermit Corp.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Enamels**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc. R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Porcelain Enamel and Mfg. Co.
The Vitro Mfg. Co.

**Enamel Oxide**
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.

**Enamels (Porcelain)**
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Equipment (Porcelain Enameling)**
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.

**Feldspar**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Eureka Flint & Spar Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Pennsylvania Pulverizing Co.
Porcelain Enamel and Mfg. Co.
The Vitro Mfg. Co.

**Filter Fabrics**
Metakloth Company

**Fire Brick**
Carborundum Co.
Corhart Refractories Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Norton Co.

**Fire Brick—Process Equipment**
Lancaster Iron Works, Inc.

**Fire Clay**
Denver Fire Clay Co.
Great Lakes Foundry Sand Co.
Spinks, H. C., Clay Co.
Thomas Alabama Kaolin Co.

**Flint**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Great Lakes Foundry Sand Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Pennsylvania Pulverizing Co.
Porcelain Enamel and Mfg. Co.

**Flint Pebbles**
Ceramic Color & Chemical Mfg. Co.
Eureka Flint & Spar Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
The Vitro Mfg. Co.

**Floors (Non-Slip)**
Norton Co.

**Fluorspar**
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**French Flint**
Eureka Flint & Spar Co.
Maxson, Elwyn L.
Paper Makers Importing Co.

**Frit**
Ceramic Color & Chemical Mfg. Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Frosting Mixtures**
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Fuel Oil Systems and Control, Stokers**
Frazier-Simplex, Inc.

**Furnaces**
Carborundum Co. (*Carboradiant*)
Denver Fire Clay Co.
Frazier-Simplex, Inc.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Swindell-Dressler Corp.

**Furnaces, Enameling**
Swindell-Dressler Corp.

**Glass Bending Ovens, Glass Decorating Machines**
Frazier-Simplex, Inc.

**Glass Equipment**
Lancaster Iron Works, Inc.

**Glass Melting Tanks and Furnaces**
Frazier-Simplex, Inc.

**Glass Sand**
Great Lakes Foundry Sand Co.

**Glass Thickness Gauge**
Bausch & Lomb Optical Co.

**Glaze and Body Spar**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Eureka Flint & Spar Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Porcelain Enamel and Mfg. Co.
The Vitro Mfg. Co.

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April and June 1936
January 1937
April and May 1938
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January 1941

**AMERICAN CERAMIC SOCIETY**
2525 North High Street, Columbus, Ohio

**Glazes and Enamels**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O , Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Glaze Spar**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Eureka Flint & Spar Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.

**Goggles**
The Hommel, O., Co., Inc.

**Gold**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

**Gold Decorations**
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.

**Granulators**
Lancaster Iron Works, Inc.
F. J. Stokes Machine Company

**Grinding Wheels**
Carborundum Co. (*Carborundum and Aloxite*)
Norton Co. (*Alundum-Crystolon*)

**Hearths**
Carborundum Co. (*Carbofrax* heat treating)
Corhart Refractories Co.
Norton Co. (*Crystolon*)

**Hearths (High Aluminous Clay, Electrically Sintered Aluminum Oxide, Silicon Carbide)**
Carborundum Co.
Norton Co.

**Hydraulic Propellers**
Denison Engineering Co.

**Hydrofluoric Acid**
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Iron Chromite**
Harshaw Chemical Co.

**Iron (Enameling)**
American Rolling Mill Co.

**Iron Oxide**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Porcelain Enamel and Mfg. Co.
The Vitro Mfg. Co.

**Kaolin**
Ceramic Color & Chemical Mfg. Co.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Thomas Alabama Kaolin Co.
United Clay Mines Corp.
The Vitro Mfg. Co.

**Kilns, China (Decorating)**
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Frazier-Simplex, Inc.
The Hommel, O., Co., Inc.
Swindell-Dressler Corp.

**Kilns (Electric, Circular, Tunnel)**
Swindell-Dressler Corp.

**Kiln Furniture (Silicon Carbide, Semi-Silicon Carbide) (Refractory)**
Electro Refractories & Alloys Corp.
Louthan Mfg. Co.

**Kryolith (see Cryolite)**
Pennsylvania Salt Mfg. Co.

**Laboratory Ware**
Norton Co.

**Lehr Tile (High Aluminous Clay, Electrically Sintered Aluminum Oxide, Silicon Carbide)**
Carborundum Co.
Electro Refractories & Alloys Corp.

**Lehrs**
Frazier-Simplex, Inc.
Swindell-Dressler Corp.

**Lehrs (Electric or Fuel Heated)**
Frazier-Simplex, Inc.
Swindell-Dressler Corp.

**Lehr Loaders**
Frazier-Simplex, Inc.

**Linings (Furnace Refractory, Block Refractory Plate, Brick, and Tile)**
Carborundum Co.
Corhart Refractories Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Norton Co.
The Vitro Mfg. Co.

**Lithium Carbonate**
Drakenfeld, B. F., & Co.
Foote Mineral Co.

**Lithium Minerals**
Foote Mineral Co.

**Loaders (Bucket)**
National Engineering Co.

**Magnesia (Fused)**
Electro Refractories & Alloys Corp.
Norton Co.

**Magnesia (Sintered, Calcined)**
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Porcelain Enamel and Mfg. Co.

**Magnesite**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

**Magnesite Calcined**
Foote Mineral Co.
The Hommel, O., Co., Inc.

**Magnesium Carbonate**
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Manganese**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

**Manganese Dioxide**
Drakenfeld, B. F., & Co.
Foote Mineral Co.

**Manganese (Oxide)**
Ceramic Color & Chemical Mfg. Co.
Corhart Refractories Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Masks (Breathing)**
Drakenfeld, B. F., & Co.

**Metals (Porcelain Enameling)**
American Rolling Mill Co.

**Micronized Products**
Porcelain Enamel and Mfg. Co.

**Microscopes (Polarizing)**
Bausch & Lomb Optical Co.
Spencer Lens Co.

**Microscopes (Stereoscopic)**
Spencer Lens Co.

**Minerals**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

**Mixers**
National Engineering Co.
F. J. Stokes Machine Company

**Mixers (Batch)**
Lancaster Iron Works, Inc.
National Engineering Co.

**Mixers (Concrete, Paving, Road Paving, Plaster, Asphalt, Truck, Mortar, Bituminous)**
Lancaster Iron Works, Inc.

**Mixers (Laboratory)**
Lancaster Iron Works, Inc.
National Engineering Co.
F. J. Stokes Machine Company

**Mold Sanders**
Lancaster Iron Works, Inc.

**Muffles (Furnace) (Laboratory)**
Carborundum Co. (*Carbofrax*)
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Frazier-Simplex, Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Norton Co.

**Mullers (Batch)**
Lancaster Iron Works, Inc.
National Engineering Co.

**Muriatic Acid**
Denver Fire Clay Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.

**Needle Antimony**
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Nepheline Syenite**
Great Lakes Foundry Sand Co

**Nickel Salts**
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Nitrates (Cobalt, Sodium)**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

**Nitre**
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

**Norbide (Norton Boron Carbide)**
Norton Co.

**Olivine**
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.

**Opacifiers**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc. R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Metal & Thermit Corp.
Pennsylvania Salt Mfg. Co.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Overglaze Colors**
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.

**Oxides**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Metal & Thermit Corp.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Palladium Decorations**
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.

**Pins**
The Hommel, O., Co., Inc.
Industrial Ceramic Products, Inc.
Ingram-Richardson Mfg. Co. of Indiana. Inc.
Louthan Mfg. Co.
Potters Supply Co.

**Pins (Tile Setter)**
Louthan Mfg. Co.

**Placing Sand**
Great Lakes Foundry Sand Co.
Pennsylvania Pulverizing Co.
United Clay Mines Corp.

**Platinum Decorations**
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.

**Polariscopes**
Bausch & Lomb Optical Co.
Frazier-Simplex, Inc.

**Porcelain Enameling Service (Practical)**
American Rolling Mill Co.
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana Inc.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Porcelain Enamels**
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

**Potters Wheels**
Denver Fire Clay Co.

**Potash (Carbonate)**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
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Chemical Engineer with over fifteen years' experience in the Glass Bottle Industry as Superintendent, Manager and Executive is open for immediate engagement. Can give highest references as to ability, character and financial standing. Can make a substantial investment. Address Box 199F, American Ceramic Society, 2525 N. High St., Columbus, Ohio.

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Montgomery Porcelain Products Co.
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Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
McDanel Refractory Porcelain Co.
Montgomery Porcelain Products Co.
Norton Co.
**Pyrometers (Optical, Radiation, Surface, Immersion, Needle)**
Leeds & Northrup Co.
Pyrometer Instrument Co.
**Pyrometric Cones**
The Edward Orton, Jr., Ceramic Foundation
**Racks, Firing (Refractory)**
Louthan Mfg. Co.
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Lancaster Iron Works, Inc.
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Electro Refractories & Alloys Corp.
Spencer Lens Co.
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Carborundum Co.
Corhart Refractories Co.
Denver Fire Clay Co.
Louthan Mfg. Co.
Norton Co.
**Refractory Materials**
American Lava Corp.
Carborundum Co.
Corhart Refractories Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Louthan Mfg. Co.
Norton Co.
Thomas Alabama Kaolin Co.
Titanium Alloy & Mfg. Co.
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The Hommel, O., Co., Inc.
**Rutile**
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Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Foote Mineral Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
The Vitro Mfg. Co.
**Saggers**
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Electro Refractories & Alloys Corp.
Norton Co.
Potters Supply Co.
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Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.
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Lancaster Iron Works, Inc.
**Saponin**
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National Engineering Co.
**Selenite of Sodium**
Drakenfeld, B. F., & Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.
**Selenium**
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Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.
**Setters (Tableware)**
Louthan Mfg. Co.
**Sheets (Enameling Iron)**
American Rolling Mill Co.
**Silica (Fused)**
Electro Refractories & Alloys Corp.
The Hommel, O., Co., Inc.
**Silicate of Soda**
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
**Silicon Carbide**
Carborundum Co.
Electro Refractories & Alloys Corp.
Norton Co.
**Silicon Carbide Firesand**
Carborundum Co.
**Sillimanite Refractories**
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
**Slab Pushers—Hydraulic**
Spencer Lens Co.
**Slabs (Furnace)**
Carborundum Co.
Electro Refractories & Alloys Corp.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Norton Co.
**Soda Ash**
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.
Solvay Sales Corp.
The Vitro Mfg. Co.
**Sodium Antimonate**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
The Vitro Mfg. Co.
**Sodium Fluoride**
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.
**Sodium Metasilicate**
Harshaw Chemical Co.
**Sodium Nitrite**
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
**Sodium Silica Fluoride**
Ceramic Color & Chemical Mfg. Co
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
**Sodium Uranate**
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
**Soot Blowers**
Frazier-Simplex, Inc.
**Special Machines**
Frazier-Simplex, Inc.
**Spar**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Eureka Flint & Spar Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Pennsylvania Pulverizing Co.
The Vitro Mfg. Co.
**Spray Booths**
The Hommel, O., Co., Inc.
**Spraying Equipment**
The Hommel, O., Co., Inc.
**Spurs**
Louthan Mfg. Co.
Potters Supply Co.
**Stacks**
Lancaster Iron Works, Inc.
**Steel Plate Construction**
Lancaster Iron Works, Inc.
**Stilts**
The Hommel, O., Co., Inc.
Industrial Ceramic Products, Inc.
Louthan Mfg. Co.
Potters Supply Co.
**Sulfuric Acid**
Denver Fire Clay Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.
**Talc**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
International Pulp Company
Paper Makers Importing Co.
**Tanks**
Frazier-Simplex, Inc.
**Tank Blocks**
Corhart Refractories Co.
**Tanks (Pickle)**
The Hommel, O., Co., Inc.
**Tanks for Raw Material Steel or Concrete**
Lancaster Iron Works, Inc.
**Tile (Floor)**
Norton Co.
**Tile (Muffle)**
Carborundum Co.
Electro Refractories & Alloys Corp.
Norton Co.
**Tile Setter Pins**
Louthan Mfg. Co.
**Tile (Refractory)**
Carborundum Co. (*Carbofrax*)
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Norton Co.
Thomas Alabama Kaolin Co.
**Tile (Wall)**
Denver Fire Clay Co.
Thomas Alabama Kaolin Co.
**Tin Oxide**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
The Vitro Mfg. Co.
**Titanium**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.
**Titanium Oxide**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.
**Trisodium Phosphate**
Harshaw Chemical Co.
**Trucks**
Lancaster Iron Works, Inc.
**Tubes (Insulating)**
Carborundum Co.
Louthan Mfg. Co.
McDanel Refractory Porcelain Co.
Norton Co.
**Tubes (Pyrometer)**
Carborundum Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
McDanel Refractory Porcelain Co.
Montgomery Porcelain Products Co.
Norton Co.
**Uranium Oxide**
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
**Uranium Oxide (Yellow-Orange-Black)**
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.
**Water Softening Plants**
Frazier-Simplex, Inc.
**Wet Enamel**
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Porcelain Enamel and Mfg. Co.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.
**Whiting**
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Paper Makers Importing Co.
The Vitro Mfg. Co.
**Winding Drums**
Lancaster Iron Works, Inc.
**Zinc Oxide**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.
**Zircon**
Foote Mineral Co.
The Hommel, O., Co., Inc.
**Zirconia**
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.
**Zirconium Oxide**
Foote Mineral Co.
The Hommel, O., Co., Inc.
Titanium Alloy Mfg. Co.
**Zirkite (Natural $ZrO_2$)**
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2412 Ken Oak Road, Baltimore, Md.

Mines: Chalk Bluff, Ala. Processing Plant: Hackleburg, Ala.

| | | |
|---|---|---|
| Analysis | Loss on ignition | 13.89% |
| | Silica ($SiO_2$) | 44.74 |
| | Aluminum oxide ($Al_2O_3$) | 39.47 |
| | Titanium oxide ($TiO_2$) | 1.29 |
| | Ferric oxide ($Fe_2O_3$) | 0.55 |
| | Lime (CaO) | 0.00 |
| | Magnesia (MgO) | 0.00 |
| | Alkalis ($Na_2O, K_2O$) | 0.00 |
| Mechanical Composition | —20 microns | 98.00% |
| | —10 " | 80.98 |
| | — 6 " | 70.94 |
| | — 3 " | 54.70 |
| | — 1 " | 37.74 |
| | — 0.5 " | 21.75 |

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**English China and Ball**

**TALCS**

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# H. C. SPINKS CLAY COMPANY

Miners and Shippers of

BALL, SAGGER AND WAD CLAY

NEWPORT, KY.

November 1, 1941

Mr. Pete Potter
Comfortable Sanitary Pottery Mfg. Co.
Pottsville, U. S. A.

Dear Pete:

Have just spent a most enjoyable weekend at the American Royal Livestock Show in Kansas City.

After seeing the beautiful cattle, hogs and sheep that were entered in the show and that packed the yards every morning, you feel like America can surely feed the world—and with the best. With all this good meat to eat there is bound to be a demand for dishes.

The cattle business, like the ceramic business, is built largely on confidence. It makes you feel good to see a buyer, by the nod of his head or a few friendly words, close a deal for a $5000.00 pen of cattle as he walks away with perfect confidence that he will get what he traded for.

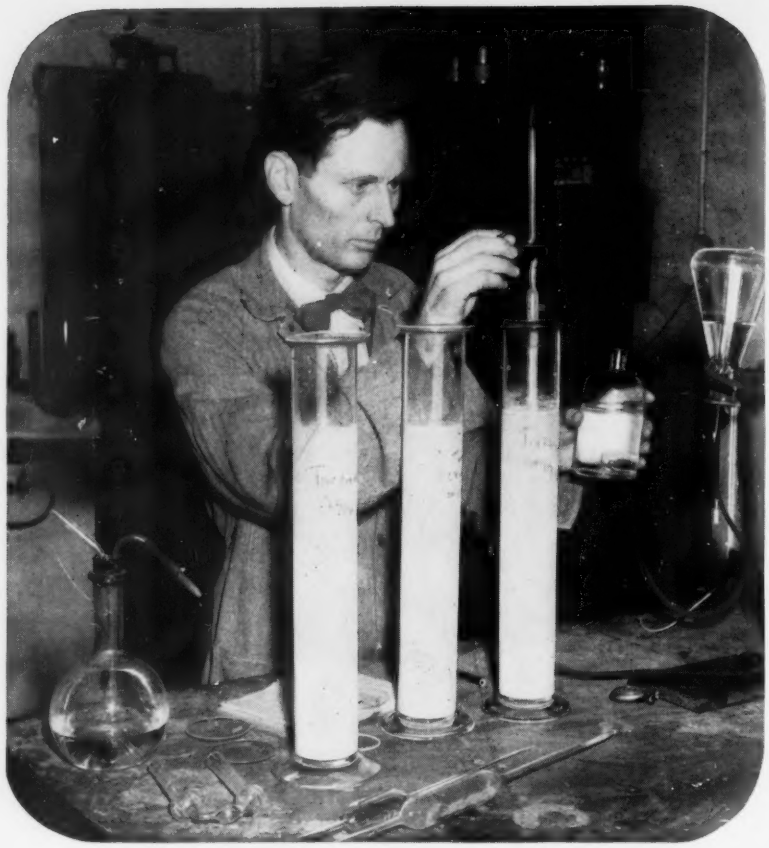
It is our greatest wish that you have just such confidence in the H. C. Spinks Clay Company and its products.

Sincerely,

Dick Carothers

General Manager
H. C. SPINKS CLAY COMPANY

RBC:MLN



Determining fineness of Tin Oxide in Metal & Thermit ceramic laboratory.

# the agate that wouldn't polish...

A phone call from an agitated manufacturer informed us that his attempts to polish agate with Tin Oxide were a failure. How could we help?

Analysis in our own ceramic laboratory revealed that the "agate" was actually "Brazilian agate" (calcite) and much softer than genuine agate. A softer grade of Tin Oxide, more suited to the purpose, was formulated which polished the Brazilian agate satisfactorily and the manufacturer was able to resume production without further delay.

As manufacturers of Tin Oxide and Sodium Antimonate it is an important part of our service to help firms solve production problems involving their use.

If you are having trouble with your glaze or enamel — or any process in which Tin Oxide or Sodium Antimonate can be used — the facilities of our laboratory are at your disposal. Inquiries are invited.

**M&T**

**TIN OXIDE**

**SODIUM ANTIMONATE**

★

The use of M & T Tin Oxide and Sodium Antimonate by many prominent ceramic manufacturers has established these opacifiers as leaders in the field. Close laboratory control assures a high degree of opacity, uniformity and a pure, brilliant finish.

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